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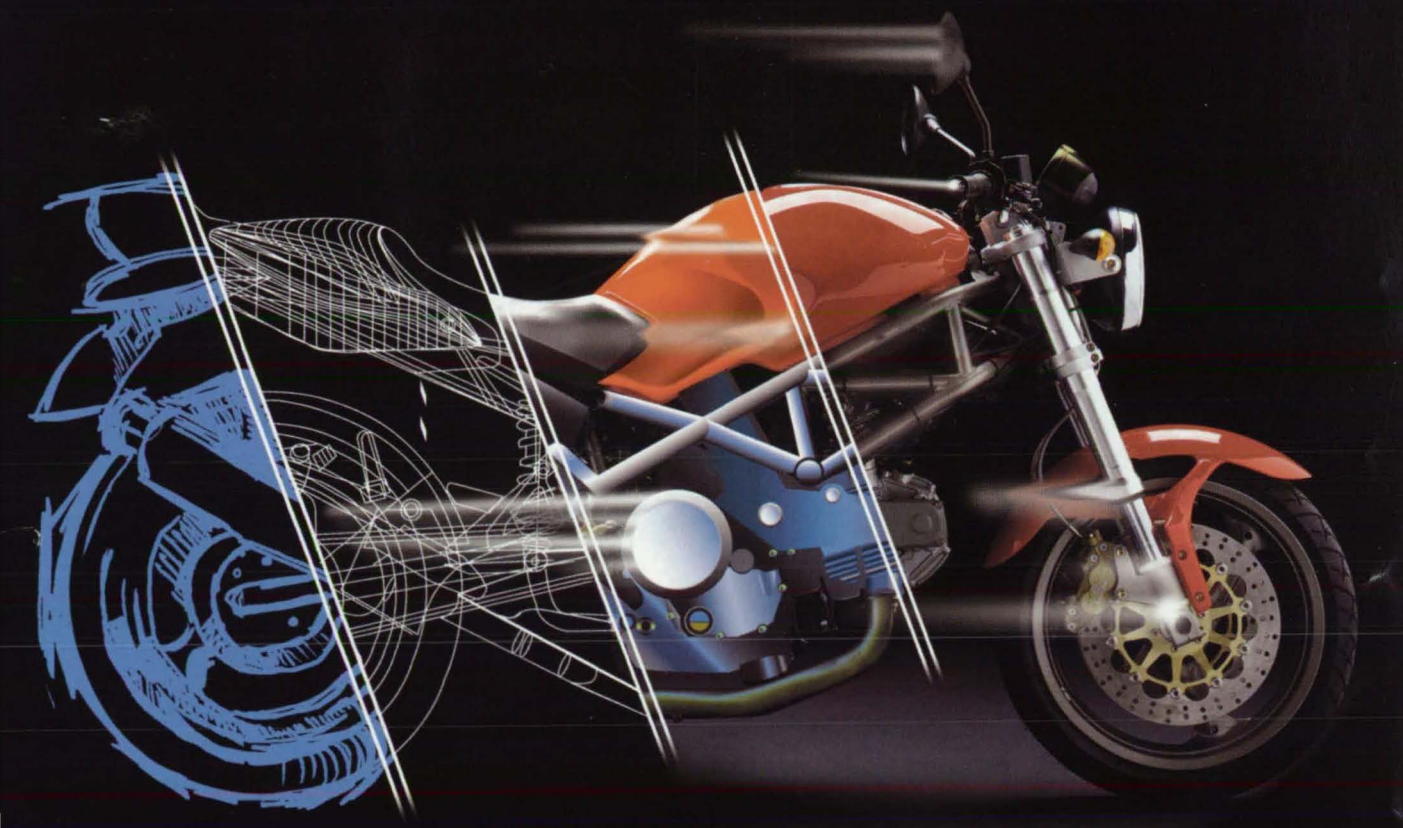

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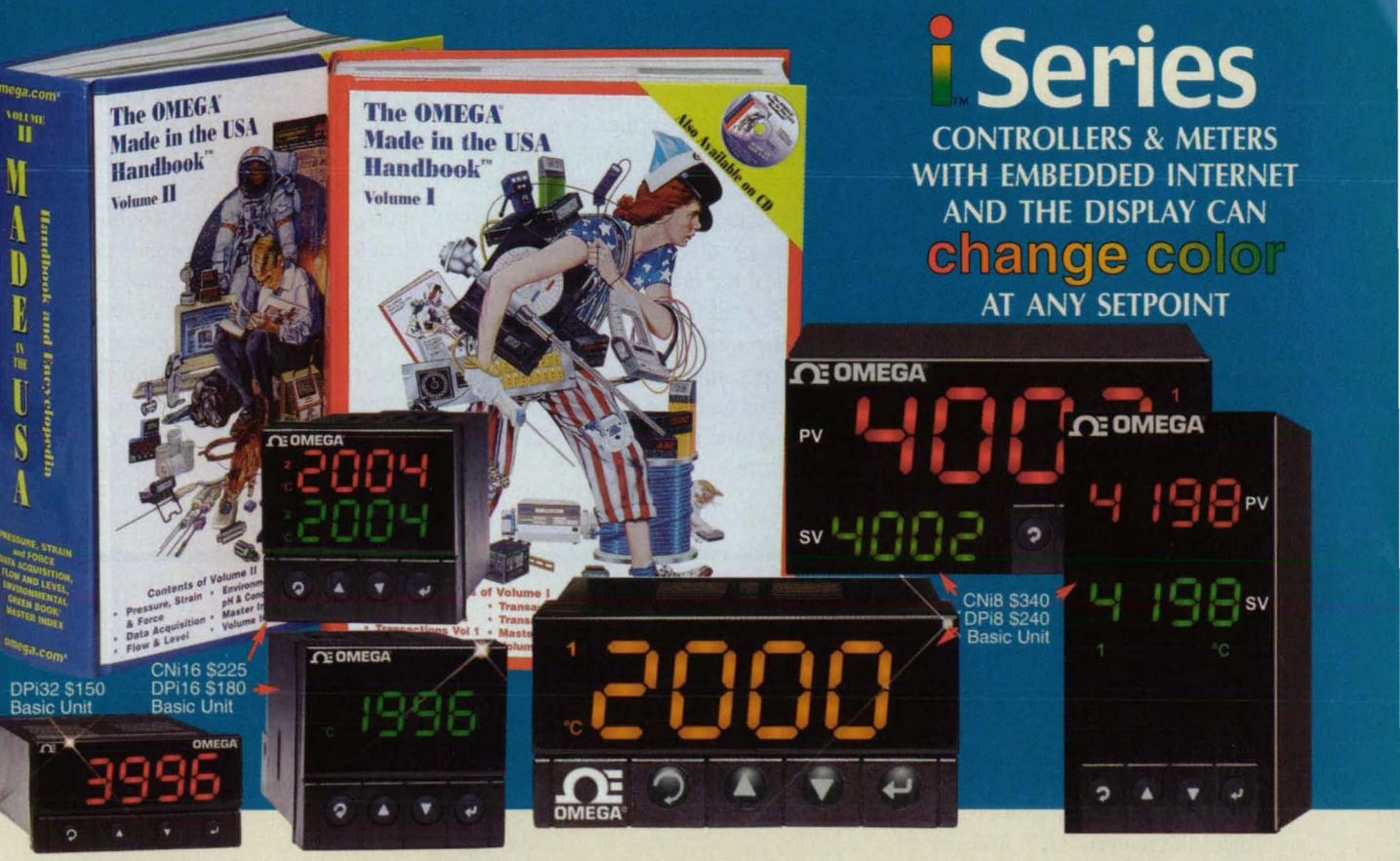

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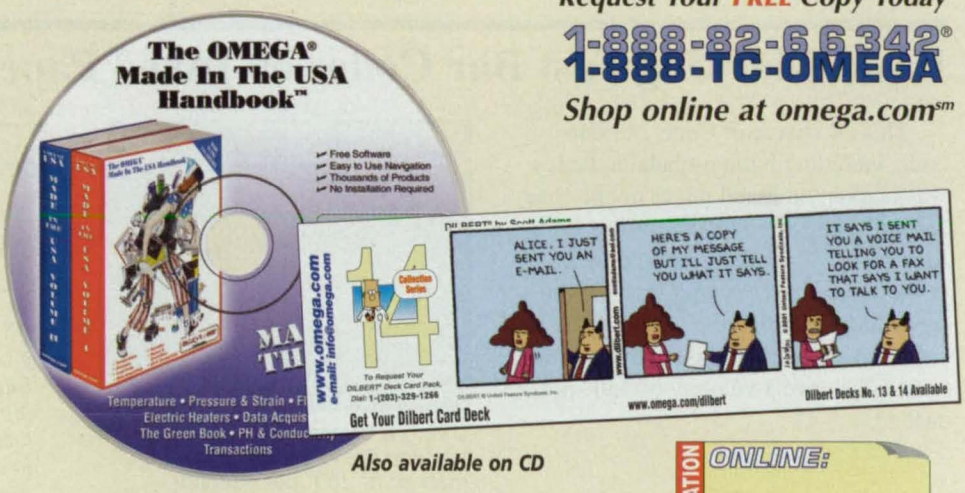

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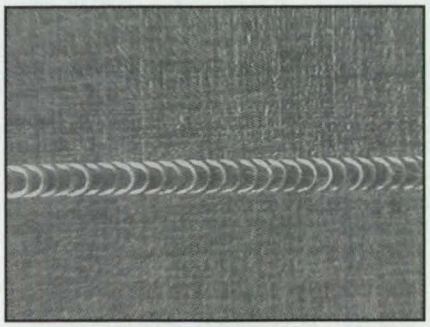

A weld created using a Synrad CO_2 laser on copper-nickel foil.

CO_2 lasers are useful in a broad range of welding applications. The photo to the left shows the results of welding 0.0025"-thick sheets of copper-nickel alloy foil. Used in aerospace, automotive, and many other industries, the material was welded with a Synrad Evolution™ 125-watt laser. The weld was made at a velocity of 110" per minute with a 2.5" focal length lens having a spot size of 0.004". Argon gas, at 2 psi, was used for shielding.

The key to achieving virtually no heat deformation and a uniform weld bead is in selecting proper pulsing parameters for the laser. In this case, a pulse frequency of 685 Hz and a pulse length of 880 microseconds provided the weld characteristics desired. Changing the thickness or width of the weld bead is simply a matter of experimenting with variations in beam velocity, pulse frequency, or pulse length.

Laser Cutting Urethane Bushings

The 2.5"-thick urethane bushing shown to the right was cut in nine seconds while being rotated underneath a 240 watt CO_2 laser beam. Although a slight discoloration is present, no charring of the urethane material occurs.

To cut the material, a 7.5" focal length lens with a 0.5" depth of focus and a 0.012" spot size was used. The bushing was rotated at 140 rpm during cutting, which took nine seconds (21 revolutions). Nitrogen assist gas at 20 psi was used while cutting.

This Urethane Bushing was cut with a 240 watt Synrad laser.

Laser Marking Fast Bar Codes on Inked Paper

This 24 character Code 128 bar code, including human-readable text, was marked on inked paper in only one second! The bar code, measuring 1.5" long by 0.5" high, was marked by a marking head and Synrad laser driven by WinMark Pro™ laser marking software. 20 watts of laser power were used to achieve a velocity of 250" per second.

Using a Synrad 25 watt marking system, these codes were marked at 250" per second!

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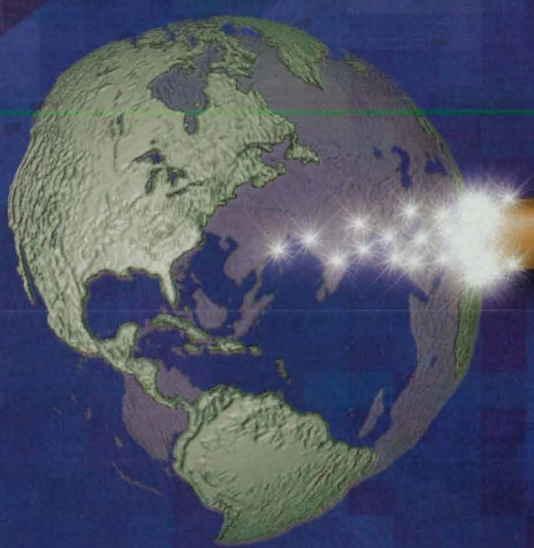

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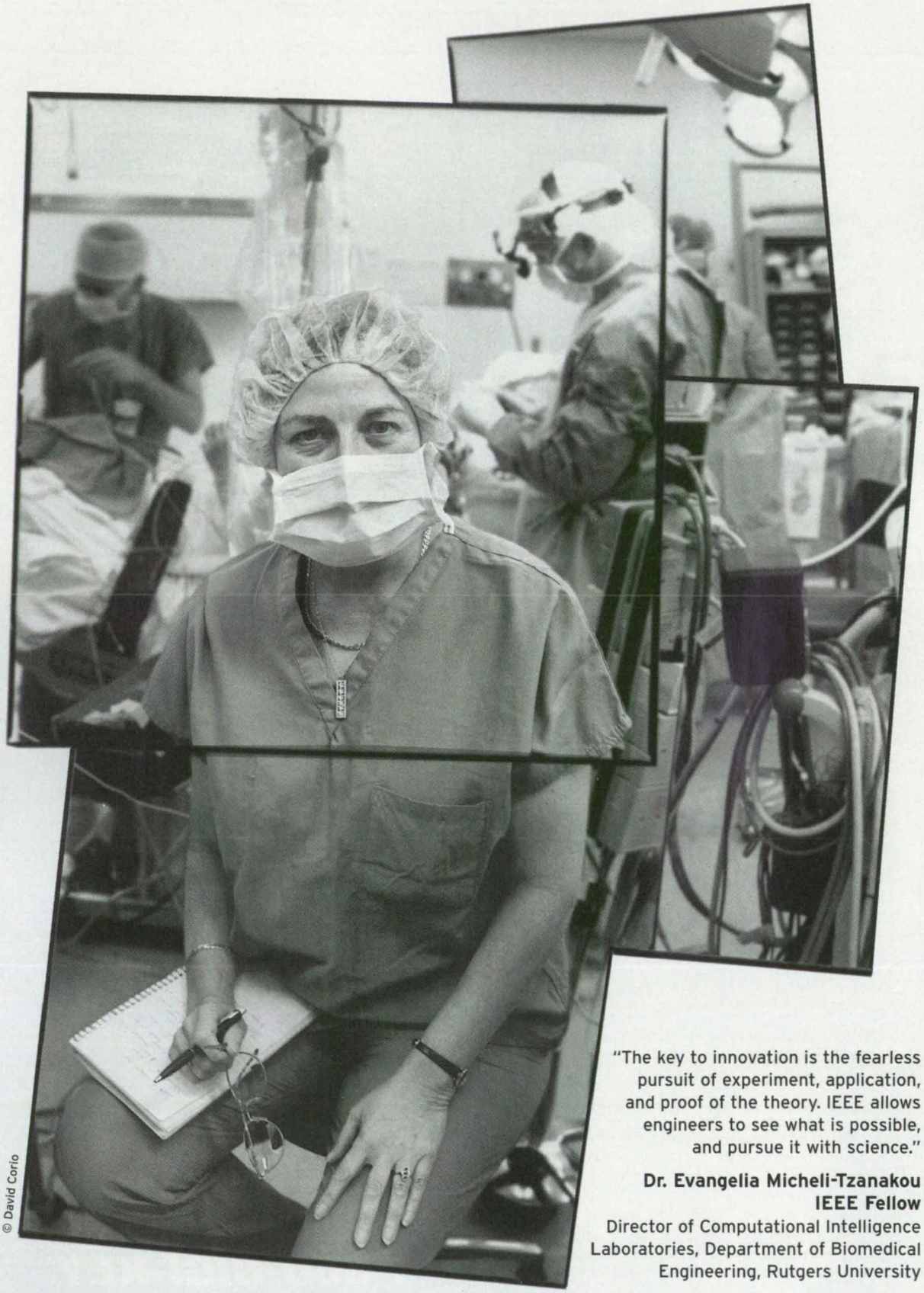

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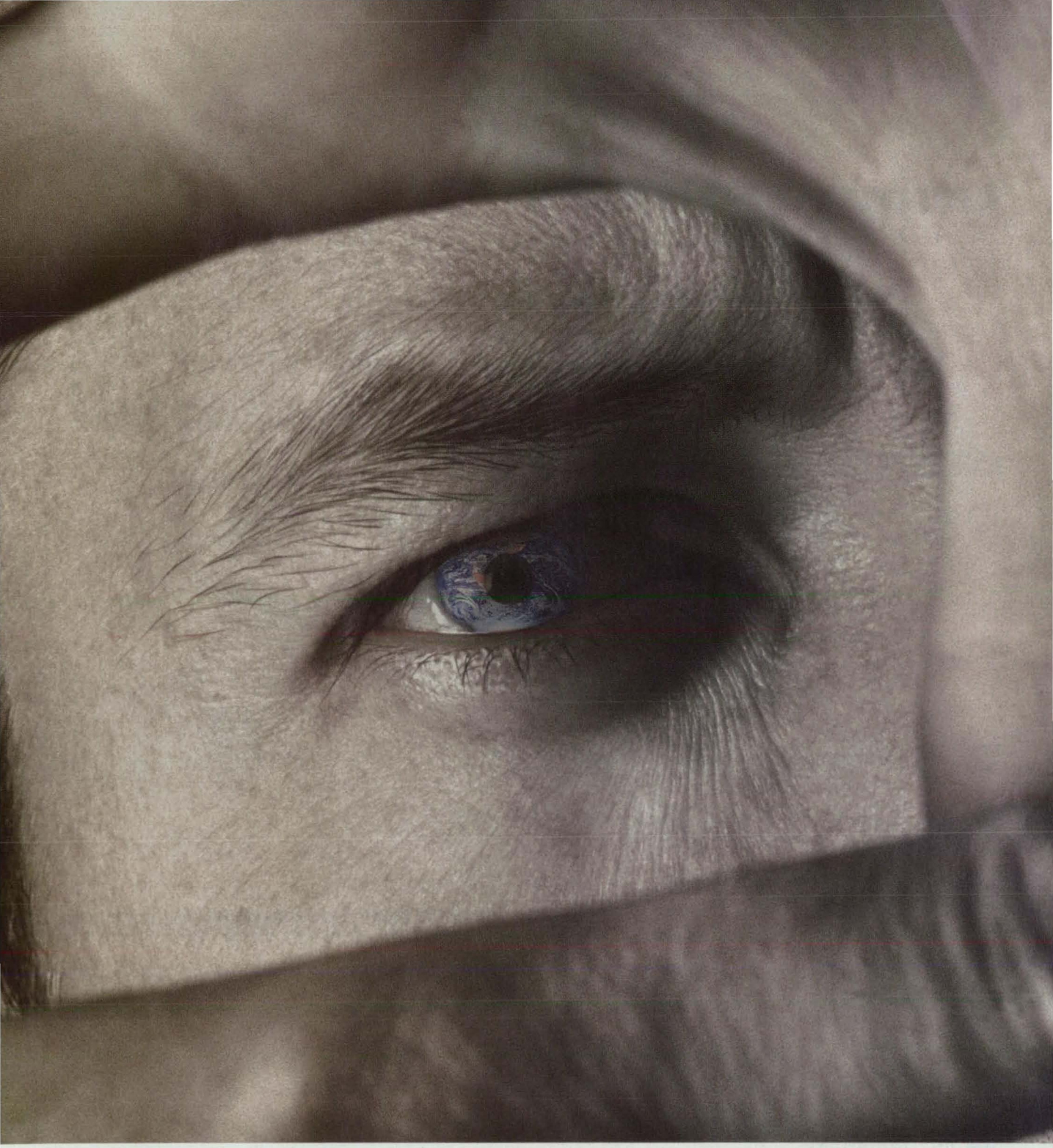

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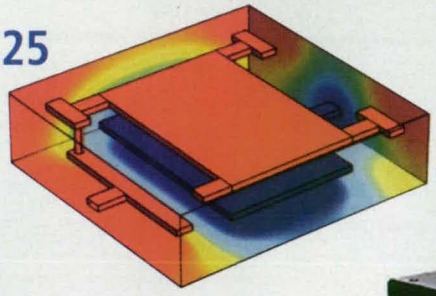


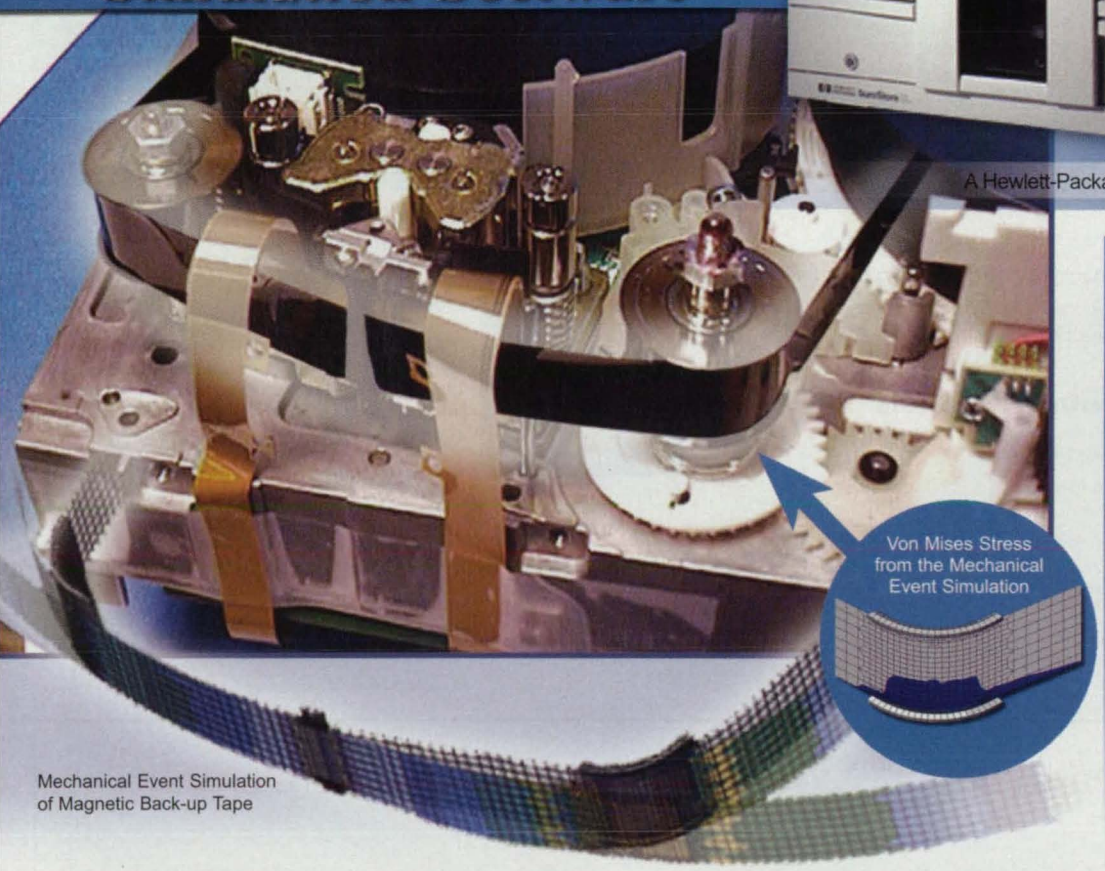
SOLUTIONS

DEPARTMENTS

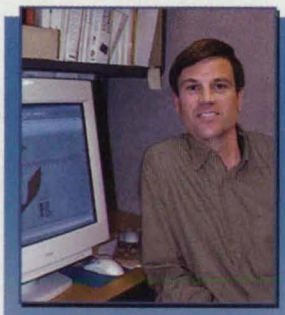
NEW FOR DESIGN ENGINEERS

Hewlett-Packard Optimizes New Tape Drive with Simulation Software

A Hewlett-Packard LTO Ultrium Back-up Drive



Mechanical Event Simulation
of Magnetic Back-up Tape



"The software's early prediction of the stress levels enabled me to make adjustments and optimize the design."

Paul Poorman
Mechanical Engineer
Hewlett-Packard Company

Hewlett-Packard Chooses ALGOR FEA to Extend the Life of Back-up Tape

Linear Tape-Open (LTO) technology, developed jointly by Hewlett-Packard Company (HP), IBM and Seagate, replaces proprietary formats for corporate back-up solutions with an open tape format that makes it easier for customers to choose products. Hewlett-Packard used ALGOR's Mechanical Event Simulation (MES) software to analyze the behavior of the magnetic recording tape as it is wound through a Hewlett-Packard LTO Ultrium back-up drive.

The Challenge

Hewlett-Packard's challenge was to optimize the LTO drive to increase tape durability while maintaining tape path stability. To study the tape's behavior, the software had to simulate motion, contact between parts in an assembly, large displacement, elastic material behavior and stresses.

For this complete story and others, visit hptapedrive.ALGOR.com

The Solution

A Hewlett-Packard engineer, Paul Poorman, modeled the magnetic tape with isotropic shell elements and the drive assembly using kinematic elements. In the MES, the tape wraps around two rollers and across a tape head and is then pulled into a take-up reel. The MES results showed the motion of the tape and resulting stresses. These results helped Hewlett-Packard find a proprietary solution that keeps the tape on track while reducing stresses on the edge of the tape, thus extending the life of the back-up tape. Paul Poorman reports, "The first generation of Hewlett-Packard Ultrium drives is currently in the market and performing well."

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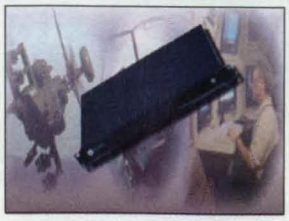

ON THE COVER

This Ducati motorcycle model was created using Windchill® Web-based product development and collaboration software from PTC, Needham, MA. The image represents the product development process, from concept to delivery. PTC's Windchill PDMLink™ product lifecycle management solution enabled Ducati to control and leverage all of its product data throughout each stage of the design-to-manufacturing process. For more information on Windchill PDMLink, see New on the Market on page 64.

(Image courtesy of Ducati North America and PTC)

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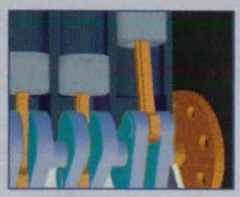

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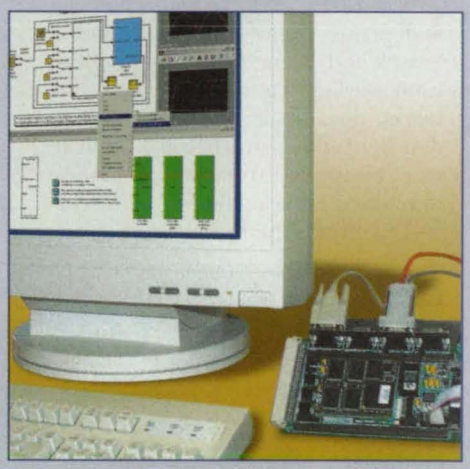

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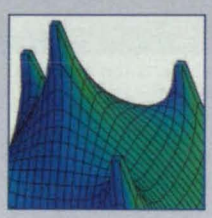

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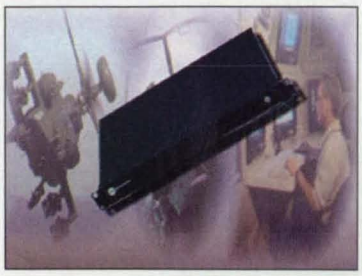

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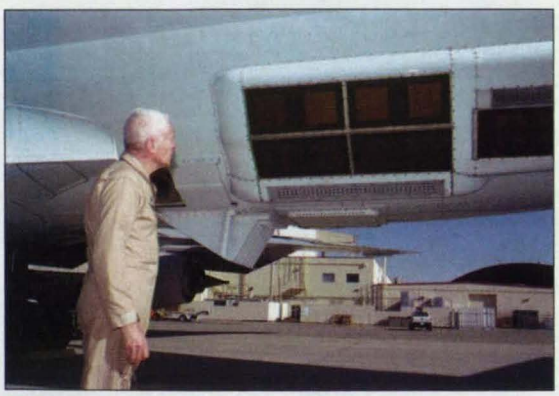
NASA Radar to the Rescue

On a dark, stormy night, a small plane crashes in the mountains. Search and rescue teams can't deploy until daylight, and even when the search does begin, the plane is hidden beneath so much brush, that it can't be spotted from the air. NASA-developed radar could be the rescue tool that finds the lost plane.



Pilot Edwin Lewis inspects the antenna for the Airsar instrument, mounted behind the wing on NASA's DC-8 airborne lab.

Scientists and engineers at NASA's Jet Propulsion Laboratory in Pasadena, CA — along with NASA's Search and Rescue Mission Office at Goddard Space Flight Center in Greenbelt, MD — are working to see if Synthetic Aperture Radar (SAR) can detect remote crash sites. Currently, a two-ton Airsar (Airborne SAR) instrument flies on NASA's DC-8, based at Dryden Flight Research Center in Edwards, CA.

The side-looking radar can penetrate through clouds, brush, and forests, and can operate both day and night. Unlike conventional radar, SAR uses a shorter antenna combined with data processing to achieve the proper image detail. Although SAR technology is 40 years old, scientists are working to increase the radar's resolution and speed the time required to process the data. Someday, radar could be carried aboard a search aircraft, an unmanned aerial vehicle, or even a satellite.

For more information on Airsar, visit http://airsar.jpl.nasa.gov.

What's New On-Line

Each month in *NASA Tech Briefs*, we include a Technology Focus section that features tech briefs devoted to a particular subject. Starting with this month's Technology Focus on Computers, you can link to a new page on the NTB Web site that highlights hot products in that same subject area.

The Technology Focus Products page at **www.nasatech.com/techfocus** includes descriptions and photos of new commercial products, along with links to the vendors' Web sites. From the products page, you can also link directly to the available Technical Support Packages (TSPs) for the briefs appearing in each issue's Technology Focus in NTB.

Check out this new, exclusive Web feature at **www.nasatech.com/techfocus**.

Take a look at the new navigation tools available for *NASA Tech Briefs*' PDF edition. Download a free sample of NTB's PDF edition (4MB) at **www.qmags.com/ntb** and test out new built-in features, including an easy-to-use navigation bar at the bottom of every page, and an automated table of contents that instantly brings you to articles of interest.

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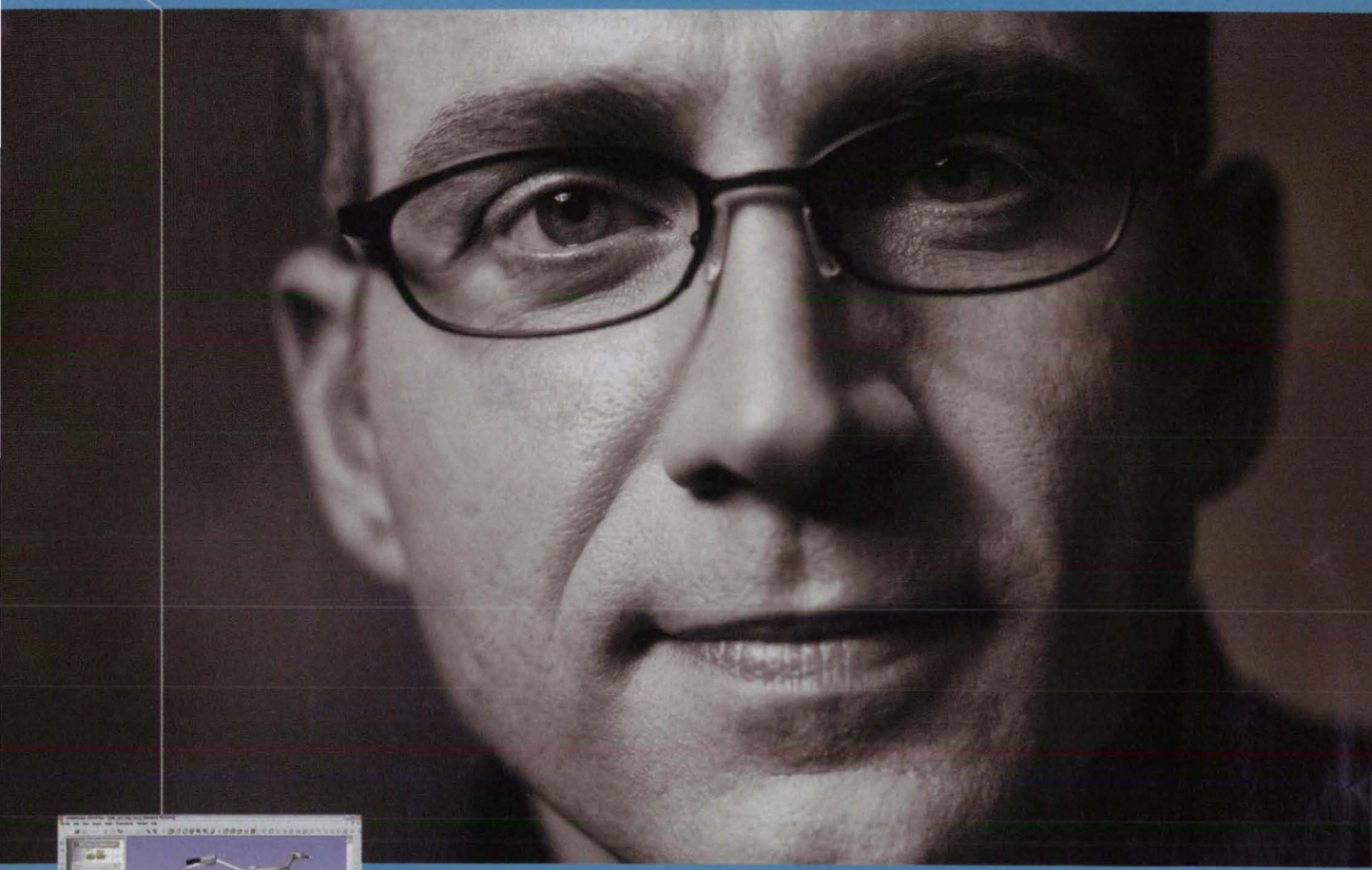
Next Month in NTB

Look for our feature article on Computer Hardware in the September issue. We'll focus on the latest and greatest computing tools available for engineers, from high-end workstations to rugged laptops and tablet PCs.

They're convinced their adaptive technology for 3D CAD software is breaking new ground.

We're convinced you aren't that gullible.



Don't confuse the latest marketing hype with true innovation. If you need a new CAD system to get new products to market faster, make sure to do your homework. When you do, you'll discover that not all 3D tools are created equal. You'll also discover a software company that genuinely listens to its customers, and with each new release, gives them the capabilities they request. That's because the people who founded this company—SolidWorks Corporation—are designers and engineers just like you.

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I'm looking for information on ultrasonic drilling and its applications for glass and quartz. Thanks in advance for any assistance.

S. Suavek
suavek_s@hotmail.com

*(**Editor's Note:** NASA's Jet Propulsion Laboratory in Pasadena, CA, has done a substantial amount of research into ultrasonic drilling, and recently developed an ultrasonic drill/corer that uses low power and low pressure on the bit, drilling rocks as hard as granite. You can find out more about this device in the tech brief available through the* NASA Tech Briefs *Web site at: www.nasatech.com/Briefs/Jan01/NPO20856.html.)*

Technologies Wanted

Periodically in Reader Forum, we feature abstracts of Demand-Pull Technology Transfer projects. These projects identify technology needs within an industry segment — such as Augmentative Communication — and find solutions to meet those needs. The Rehabilitation Engineering Research Center on Technology Transfer, in partnership with the Rehabilitation Engineering Research Center on Communication Enhancement and the Federal Laboratory Consortium, has developed the Project on Communication Enhancement to identify technologies like those listed below to help persons with communication disabilities who use Augmentative Communication devices. For more details on the project, or to submit technology proposals, visit **http://cosmos.buffalo.edu/aac.**

Communications Processing

Augmentative and alternative communication (AAC) systems need advanced processing capabilities in order to improve the rate and quality of communication. AAC systems should be transparently usable out of the box with advanced capabilities learned in a natural, intuitive manner.

Communication processing should support the construction of language at an appropriate level. Capabilities should include smart syntactic and semantic editing; hyperlinks from composed text to databases, references, and pre-stored text; efficient error correction; and access to a dictionary and thesaurus. The communication processing should efficiently store, find, retrieve, merge, and modify text in order to improve the rate and quality of communication and literate composition.

Persons using AAC systems also need wireless access to and control of personal computers, the Internet, cell phones, appliances, and home security.

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Dr. Edward Snell, Senior Scientist, Laboratory for Structural Biology, Marshall Space Flight Center

Dr. Edward Snell is a Senior Scientist in the Laboratory for Structural Biology at NASA's Marshall Space Flight Center in Huntsville, AL. As a crystallographer, he is attempting to map the structure of disease-causing proteins.

NASA Tech Briefs: What is the novelty of this particular research?

Dr. Edward Snell: Microgravity offers us an environment that has been shown to grow crystals that are physically more perfect than those on the ground. We crystallize biological macromolecules that are important in understanding how diseases are caused and how they can be stopped. From X-ray analysis of the crystals and a lot of hard work, we can get a picture of the macromolecule.

In collaboration with Dr. Gloria Borgstahl at the University of Toledo, we have been studying how the better ordering occurs and what physical effects that has on the crystals. We have been looking at insulin and developed new techniques to characterize the microgravity improvements rapidly and statistically. NASA has provided a grant to Dr. Borgstahl for this research, which has provided the seed funding for further investigations into other macromolecules, notably some responsible for cancer.

NTB: What are the advantages of growing crystals on the International Space Station?

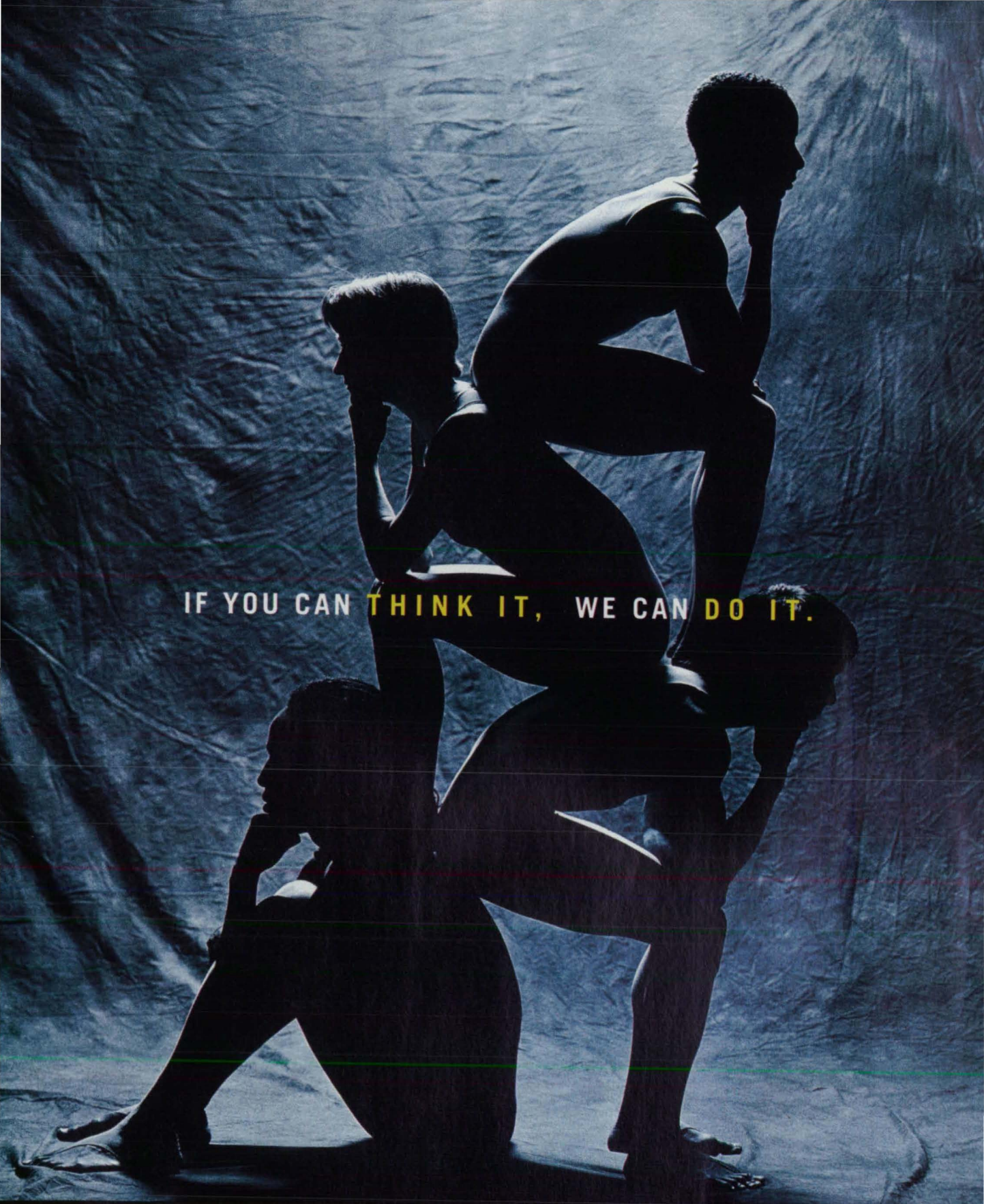
Dr. Snell: Back in 1981, a sounding rocket was used to grow a protein in microgravity while it was filmed with a special camera. During the short period of growth, clear differences were seen in the growth from that on the ground. The film showed smooth fluid flow around the crystal compared to turbulent convection on the ground. Our own studies with six microgravity and six ground-grown insulin crystals gave microgravity crystals averaging 34 times larger volume with seven-fold improvement in crystal quality, resulting in improved structural detail.

We could grow the insulin crystals on the short duration of the shuttle mission, but many crystal growth experiments need a longer time. The Space Station gives us this time. It also allows the potential for a much more exciting experiment. At present, when we grow crystals in the laboratory, we look at the results and start a new experiment using the knowledge from our observations to optimize the crystals. Our first crystal may not be suitable for X-ray analysis and several iterations may be needed. With the shuttle, you had to wait until it came back, analyze the results, and wait until the next mission. With the long-duration missions of the Space Station we may be able to do science as we do it in the laboratory. Our experiments are very small; over a hundred could fit in a shoebox. The potential from them is very high depending on the sample being studied, which makes them ideal for microgravity.

NTB: What will this research mean for the treatment of cancer and diabetes?

Dr. Snell: Structural crystallography provides the picture of the macromolecule. Once scientists have the picture, they can understand how the macromolecule works and can design a drug to stop or aid its function. A lot of work has gone into improving the quality of life for diabetes patients. The insulin we are studying is part of that work. Work on cancer, for which Dr. Borgstahl has just received funding, will advance the knowledge of that disease. With enough knowledge comes the treatment or cure, but we'll have to wait a while, unfortunately. The whole process from crystal to structure, and maybe a new drug, takes many years. Microgravity crystals giving more details help the process.

A full transcript of this interview appears online at ***www.nasatech.com/whoswho****. Dr. Snell can be reached at eddie.snell@msfc.nasa.gov.*



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Launching the shuttle involves various critical steps, including many preparations that precede the actual flight. Moving the spacecraft into place is one of the more significant undertakings. Using a massive Crawler/Transporter, the Mobile Launching Platform and the shuttle orbiter are slowly carried from the Vehicle Assembly Building to the launch pad.

To keep the shuttle level on its way to the launch pad, several Trans-Tek angular displacement transducers (ADTs) will be incorporated into the transporter's leveling and steering systems. The ADTs are replacing rotary potentiometers, which did not satisfy specified accuracy requirements and wore out too quickly.

The ADTs will be used for angular position feedback on servovalves located throughout the crawler. Some of these servovalves are linked to pump drives that control the steering function for each of the four double-tracked bogies. Other servovalves control the jacking, equalizing, and leveling of the launching platform as the transporter negotiates a 5% ramp leading up to the launch pad. The tip of the orbiter is kept vertical within ten minutes of an arc, or about the diameter of a basketball, during the five-hour journey to the launch pad.

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Video Guidance Sensor Helps Satellite Docking

Advanced Video Guidance Sensor (AVGS)
Advanced Optical Systems
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www.aos-inc.com

NASA's Demonstration of Autonomous Rendezvous Technology (DART) was created to locate and rendezvous with other spacecraft without direct human guidance. While NASA has performed rendezvous and docking missions in the past, astronauts have always piloted the spacecrafts. The autonomous rendezvous capabilities demonstrated by DART will lay the groundwork for future reusable manned and unmanned launch vehicle operations.

The DART vehicle will be launched and inserted into a circular parking orbit. The vehicle will then perform a series of orbit transfers to arrive at a point near a target satellite using GPS navigation. The vehicle's main instrument is the Advanced Video Guidance Sensor (AVGS), an optical sensor with no moving parts that provides 6-degree-of-freedom information at 75 Hz update rates for autonomous docking of a chase vehicle with orbiting satellites possessing passive target clusters.

Designed by Advanced Optical Systems and Orbital Sciences' Technical Services Division, the AVGS consists of a monostatic optical transceiver with four 1-watt diode lasers multiplexed into a single-fiber emitter to illuminate a ±12° aperture in front of the chase vehicle. Optically reflective corner cubes are mounted on the target satellite and arranged in a triangle pattern with the

optical axis of all three corner cubes pointed in the same direction. Laser light reflected by the corner cubes is collected by an imaging lens and projected onto a 1024 x 1024 CMOS imager. Pattern recognition algorithms identify the spot centroids of each corner cube to determine range, bearing, and attitude of the chase vehicle with respect to the target satellite. Electronics reduce the amount of imager data to provide relative navigation information over an RS-422 serial communications port to the on-board computer.

Using the AVGS, DART will approach the target satellite within a distance of 15 meters and perform a station keep maneuver. Finally, the vehicle will demonstrate a collision avoidance maneuver, then depart the vicinity and transition to its final orbit. The entire sequence will be accomplished under autonomous control and is partially enabled by the AVGS.

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Technologies of the Month

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Water-Based Binder System Enables Fast, Low-Cost Ceramic Injection Molding

Honeywell

Ceramics have been instrumental in the manufacture of critical components in electronics, avionics, and transportation. However, the process to create ceramic parts has been slow, costly, and inefficient. One solution is injection molding usually composed of wax and plastic binders.

A binder made from water and agar — an organic, sugar-based gum — has proven to have many advantages over conventional binders including use of low-cost OTS injection-molding equipment, lower molding pressure for less part stress and longer mold life, formation of both thick- and thin-walled complex parts, no toxic waste stream, and no binder burn-out stage.

Get the complete report on this technology at:
www.nasatech.com/techsearch/tow/Honeywell-binder.html
Email: nasatech@yet2.com
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Pressure-Sensitive Paint for Wind Tunnel Testing

BAE SYSTEMS Advanced Technology Centre

Wind tunnel testing has been an accurate method of verifying the design of virtually anything that moves or is subjected to high winds such as cars, trucks, aircraft, spacecraft, ships, and buildings. However, traditional wind tunnel testing requires expensive, time-consuming pressure-plotted models that incorporate multiple embedded sensors in fixed locations in the model's surface.

A new technology called SUPREMO combines pressure-sensitive paint and laser excitation, providing data and analysis over a greater surface area than conventional testing methods and simplifying model construction. A collinear photodetector measures and records the phosphorescent decay at multi-kilohertz rates, providing near-real-time analysis of the pressure exerted upon the surface area of the model.

Get the complete report on this technology at:
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Encrypted Video Surveillance Technology Assures Privacy Rights

KPN

There is a legitimate need for a certain level of surveillance to protect communities, citizens, property, companies, and organizations. The challenge is to balance this need with the concern for privacy. An encrypted video surveillance system ensures both the privacy of individuals and the ability of business and government agencies to prevent theft and damage. The key component of this system is the BGR PrivaCAM, a digital camera that takes recorded images and divides them into a series of discrete information streams. Using an encryption method called "secret sharing," these data streams are separated and sent to several different, authorized recipients. By themselves, the streams are useless, making it impossible to reconstruct the image. The device is used where a video record of events or a passive monitoring of activities is required.

Get the complete report on this technology at:
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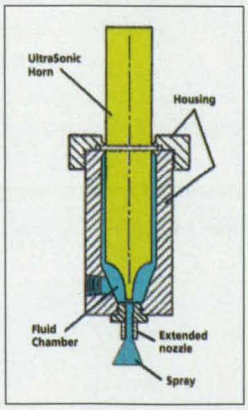
Improved Liquid Flow Through an Orifice

Kimberly-Clark

Composed of an ultrasonic horn immersed in a pressurized liquid chamber and an extended nozzle, a proprietary application of ultrasonic energy improves efficiency and throughput of spray and flow nozzles by applying ultrasonic energy to the liquid. Ultrasonic energy applied to the horn changes the liquid viscosity near the exit orifice without vibrating the orifice or nozzle body.



In tests, this technology demonstrated increased nozzle flow rate, increased velocity and penetration of the droplets, decreased average diameter of the droplets, decreased size distribution of the droplets, and decreased viscosity of the liquid at the point of injection. Applications include high-volume fuel injectors, turbine combustors, spray drying, coating applications, and plastic extrusion.

Get the complete report on this technology at:
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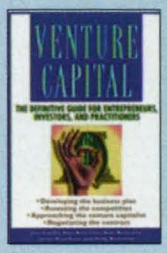

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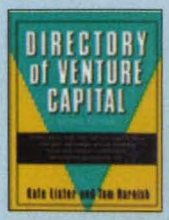

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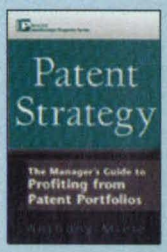

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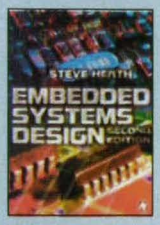

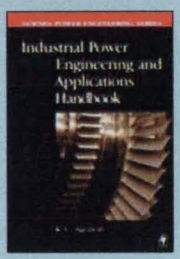

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The Future of MEMS:

Big Expectations for Small Products

Depending upon which study or report you read, the MEMS (microelectromechanical systems) market is either experiencing a booming growth, or is moving at a snail's pace. But while market predictions and dollar figures vary widely, the fact is that MEMS will continue to develop as one of the most important technologies in the 21st century.

MEMS are defined as micron-sized devices that sense or manipulate a physical environment. They are manufactured, or fabricated, using the same micromachining techniques used by the microelectronics industry. The tiny devices can range in size from just a few microns to a millimeter, and are commonly chip-level devices fabricated on silicon, similar to semiconductor manufacturing. What makes MEMS special is that they are complete microsystems on a chip that can contain moving parts, as well as optical, chemical, and electrical components. Simply, they are the smallest machines that can go where other mechanical devices cannot.

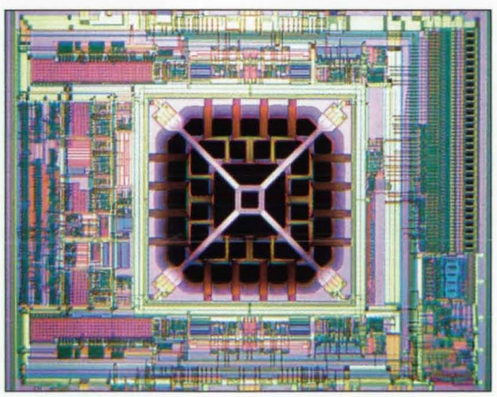
And as with any growing market, expectations often exceed reality.

The MEMS Industry Group — a trade association representing the U.S. MEMS and microstructures industries — predicts that MEMS will be an $8 to $15 billion industry by 2004. A report by Technical Insights, a division of Frost & Sullivan, recognizes a slower growth in MEMS applications than predicted.

Said Chris Bang, director of applications for MEMGen, a Burbank, CA-based company that provides manufacturing services for MEMS devices, "There's an issue of expectation. Because MEMS technology is exciting and has lots of potential, there is a tendency to say that in three years, all of a sudden there's going to be this huge explosion. That's not necessarily the case. That may not happen," Bang explained, "and that doesn't necessarily have to happen in order for a new technology to be successful."

Successful applications of MEMS devices already exist. Each time an airbag is deployed in a car accident, a MEMS device is responsible for that activation. Inkjet printers use MEMS devices to pump ink. Hospitals use blood pressure monitors that incorporate MEMS pressure sensors.

According to Bang, MEMS technology already is successful. "There are a lot of very high-volume, successful applications already." But, he added, it's not unusual for a new technology to take ten or 20 years to really come to fruition. "When people talk about MEMS being slow to commercialize, I think that it's slow relative to expectations that may not be realistic. If you look at what's in the pipeline, there are a lot of exciting new things being developed. Some things will work and some things won't pan out."



MEMSIC's MEMS-based accelerometer contains no moving parts, and combines the sensor and associated electronics on a single chip, which is manufactured on a standard, submicron CMOS process.

MEMS market research analyst, Roger Grace, agrees. "MEMS is a successful industry, but there is a long way to go. We're still very early in the evolution of the industry. Nanotechnology is a 50-year-old industry — we've grown very slowly." Grace explained that with any industry, especially such an R&D-intensive industry, "you don't take off right out of the box."

Part of the problem is getting these exciting new MEMS devices out of the laboratories and into the commercial market. While new MEMS applications and innovations have been consistently produced in research and university labs, only a small portion of those applications have resulted in commercial products. The biomedical and telecommunications industries hold the most promise for future MEMS devices, but just when those devices will be marketable is still unclear.

"There are applications surfacing," explained Grace, "but it's taking a lot longer than people, including myself, had predicted. There is no freeway to the high-volume applications that we thought would exist." Grace predicted that over time, more MEMS technology will be absorbed by the automotive industry — already a prime market for MEMS — and the consumer appliance industry.

"There are not a lot of killer applications for MEMS," according to Grace. "There are a lot of high-volume applications that people see in the future, but this is not what's happening now. This is not high-volume production, and it won't be for two or three years." Added Grace, "It's not a business where there is lots of money available. There are only a small number of killer applications, and everybody's fighting for them."

The U.S. government recognized the need for additional funding for the nanotechnology field when the Clinton Administration established the National Nanotechnology Initiative (NNI) in 2000. The NNI, which includes participation by agencies such as NASA, the National Science Foundation, and the National Institutes of Health, was designed to support long-term nanoscale research and development in areas such as electronics, the environment, energy, chemicals, agriculture, materials, manufacturing, information technology, and biotechnology. The original budget of $270 million in 2000 was increased by 83% to $495 million last year.

Making MEMS

MEMS manufacturing capacity appears to be strong, according to the Frost & Sullivan Technical Insights report. New fabrication facilities are online, and traditional semiconductor foundries are getting involved with MEMS, the report states.

"What's hot now is what's happening with the companies that are making tools," said Grace. "There are a lot of companies making semiconductor fab tools specifically for MEMS. In the past they

Collaborate to innovate– PLM Solutions

Product Lifecycle Management (PLM) solutions reduce the complexities and restrictions linked to product manufacturing. How? By providing the framework and tools that foster a collaborative, integrated, end-to-end, process-centric environment. In short, PLM brings together the entire network of companies that conceptualize, design, manufacture and support a product to work together as one single entity.

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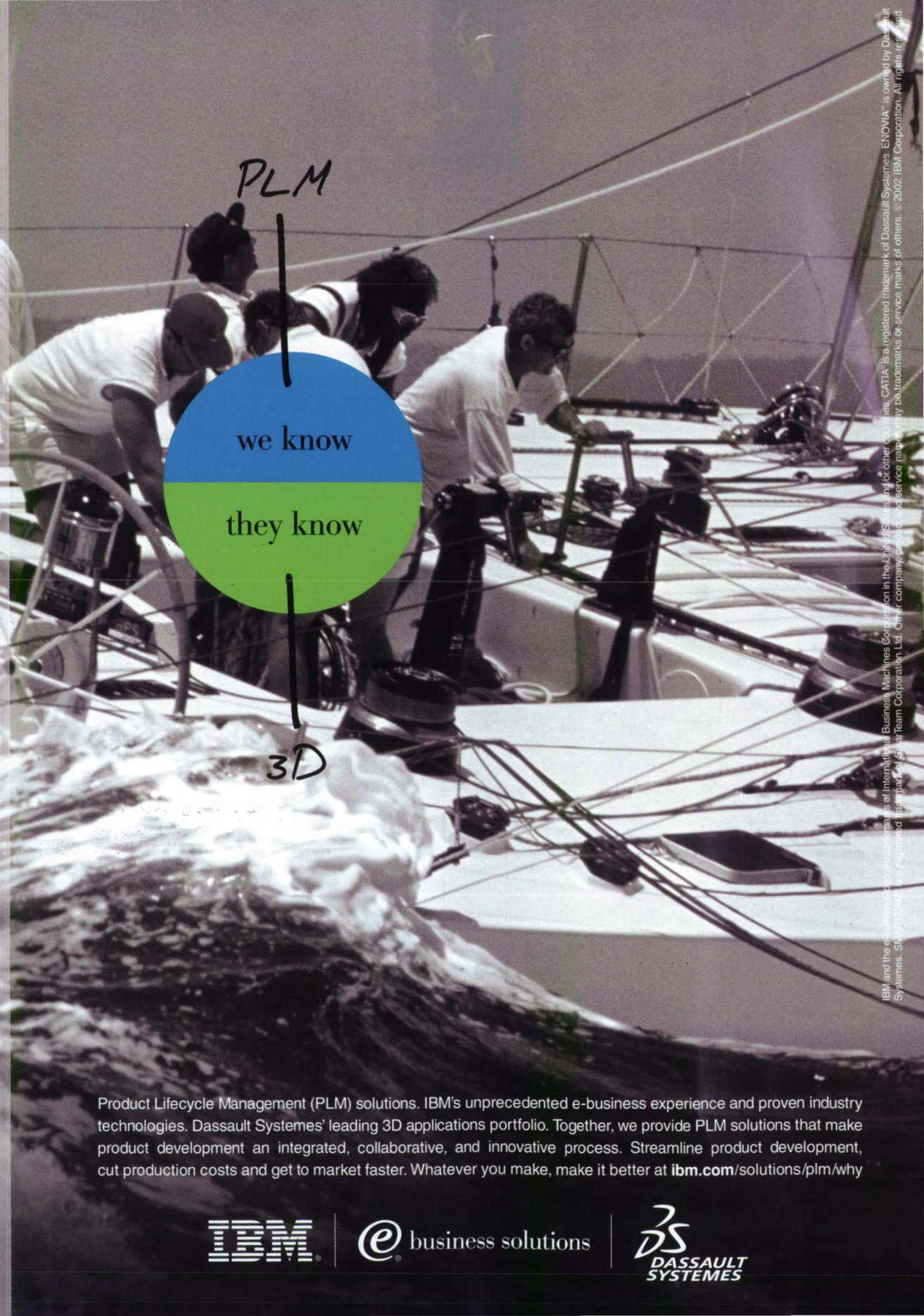

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CAD to MEMS

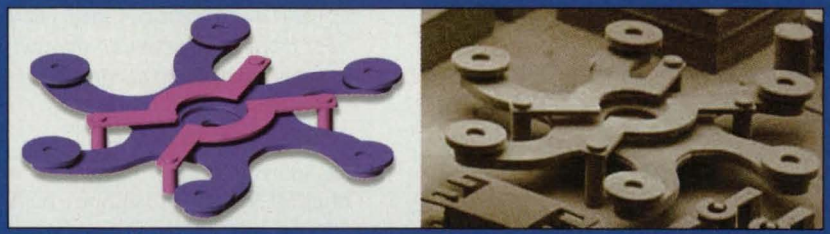
Today, most MEMS devices are manufactured using traditional micromachining. There are cleanrooms, several pieces of equipment, process engineers, and a lengthy manufacturing process that may take months to complete a single prototype. MEMGen, a Burbank, CA-based company, has developed EFAB™, a 3D micromanufacturing technology that allows fully functional MEMS devices to be produced just days after they are designed using conventional CAD software.

"The biggest problem MEMS has had is getting out of the lab and into the marketplace," said Chris Bang, director of applications for MEMGen. "It is costly, time-consuming, and complicated with the approaches that have been used." With EFAB, he explained, there is a single machine that's fully automated so it doesn't need engineers running it. Parts can be made in a matter of several days or under two weeks, rather than months.

"It is in some ways similar to the rapid prototyping paradigm in that you start with a CAD drawing of an object, and we have a standalone machine or manufacturing cell that can replicate a part from that CAD drawing," Bang explained. But with rapid prototyping, polymers are used to make models. "With EFAB," said Bang, "you can make working, fully functional MEMS devices. We give people metal parts. We can work with any electroplated material."

EFAB uses a patterning technology called Instant Masking™ to generate microstructures quickly. The technique rapidly deposits independently patterned layers. Together, the layers form virtually arbitrary, complex 3D shapes. The system lets a designer go from idea to 3D CAD model to production of a micro-product in days.

One of the big advantages of the EFAB process is that you don't have to be a microtechnology or MEMS expert. Anybody who knows how to use CAD software can design a part with EFAB. "You can use any 3D CAD package," Bang explained. "We work from an STL file, which is a format that pretty much any commercial CAD package can produce. It can be SolidWorks, Pro/ENGINEER, or any other package."

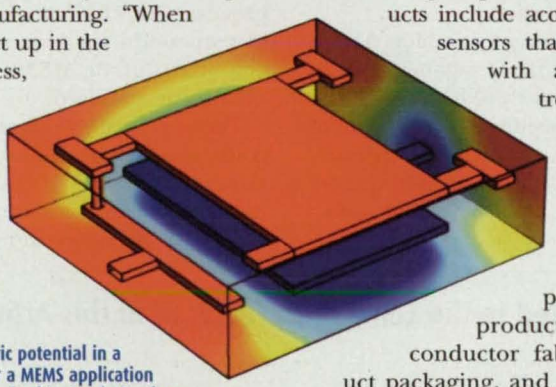


EFAB enables fabrication of micro-parts like this array of spray nozzles for a fuel injector. The CAD image used to design the parts is shown on the left. The actual nozzle array, pictured on the right, measures 2 mm across.

For more information, contact MEMGen at 818-295-3996; e-mail: info@MEMGen.com; or visit the Web site at www.MEMGen.com.

didn't do that, but over the past few years, they've realized that MEMS requirements are very unique. This is a major manufacturing trend."

Today, the capacity for manufacturing MEMS devices is outpacing the number of devices being manufactured. Companies new to the MEMS manufacturing business are taking their cue from the semiconductor industry and looking to "fab-less" manufacturing. "When companies start up in the MEMS business, they are no longer building a facility and buying fab equipment because there is so much equipment that is not being utilized," explained Grace. "There is so much capacity to make MEMS, and less than ten percent of that capacity is being utilized."



Electric potential in a capacitor for a MEMS application is shown in this simulation from COMSOL's FEMLAB software.

MEMS manufacturing facilities often are categorized by the process they use. Some specialize in surface micromachining, which uses a lithography process similar to chip manufacturing, and others use bulk micromachining, which involves etching onto wafers. Other companies produce metal parts, such as MEMGen (see "CAD to MEMS" sidebar above).

Andover, MA-based MEMSIC is a semifabless integrated circuit (IC) company that designs, manufactures, and markets MEMS IC products that have on-chip mixed signal processing. These products include accelerometers and sensors that are combined with associated electronics onto a single chip.

StandardMEMS was the first fully integrated MEMS company, providing product design, semiconductor fabrication, product packaging, and systems integration. The company has produced more than 50 million devices to the commercial market, including inkjet print heads, a DNA analysis chip, RF switches, gyroscopes, and automotive pressure sensor devices. StandardMEMS provides surface, bulk, and integrated CMOS/MEMS processing, as well as etching, metalization, thin film engineering, wafer bonding and dicing, and laser material processing.

Earlier this year, Olympus Optical announced the launch of its MEMS Foundry Services, which offers MEMS-engineered designs, prototypes, and production facilities. The San Jose, CA-based project provides companies with equipment and test capabilities such as image and photo sensors, optical scanners, and diagnostic tactile sensors, as well as small-lot production contracting services.

Before MEMS devices can be produced, they must be designed, often using MEMS-specific design software. Some companies — such as MEMSCAP and Corning IntelliSense Corp. — provide both design software and the manufacturing facilities to produce the devices.

MEMSCAP offers two MEMS design software tools: MEMS Xplorer™ for UNIX workstations, and MEMS Pro™ for PCs. The software enables designers to develop MEMS designs, integrate existing designs, and couple them with the system electronics that will drive the devices. They support leading electronic design automation tools used for integrated circuit development. Developers also can customize the software to target a particular type of foundry.

Corning IntelliSense developed the first commercial CAD for MEMS tool, called IntelliSuite™, which designs, simulates, and optimizes MEMS prior to fabrication. It incorporates process tem-

MEMS Conference Set for September

The seventh International Conference on the Commercialization of Micro and Nanosystems (COMS 2002) at the Marriott Eagle Crest Resort in Ypsilanti, MI, from September 8-12, 2002, is expected to draw more than 300 leaders in the field. Sponsored by the Micro and Nanotechnology Commercialization Education Foundation (MANCEF), the event will be attended by professionals involved in the investment and transfer of micro and nanotechnology to the marketplace, including users, suppliers, service/equipment providers, investors, and analysts.

Key issues for discussion include applications, market analysis and trends, government policy, industry standards, manufacturing resources, venture capital funding, and cost models. Panel discussions and speeches will be given by prominent industry professionals.

For more information on the technical program, speakers, exhibitor opportunities, accommodations, and to register online, visit the Web site at: www.coms2002.org.

plates, material data, mask layout, and device analysis.

Other MEMS-specific software has been introduced by traditional simulation and analysis software vendors. ALGOR, Inc. offers a MEMS simulation solution called Professional MEMS Simulation that links electrostatic analysis to stress analysis tools. The package enables engineers to simulate the real-world behavior of MEMS devices using its Mechanical Event Simulation (MES). MES simultaneously replicates the dynamic flexing behavior of a component or mechanism to predict stresses that may result from motion or from the interaction of the part with other independent objects.

FEMLAB®, a scientific modeling and simulation environment from COMSOL, has a multiphysics feature that lets users simultaneously model any combination of phenomena, an ability that is crucial in the MEMS field. These phenomena include electromagnetics, structural mechanics, fluid mechanics, transport phenomena, and acoustics.

Simulation software supplier ANSYS features MEMS analysis capabilities in its ANSYS/Multiphysics product, which has physics capabilities directly applicable to areas of microsystem design. Key features include electrostatics, high-frequency electromagnetics, and electrostatic-structural coupling.

A Standard Problem

One thing the MEMS industry lacks today is standards. Since there are so many diverse applications for MEMS devices and technologies, composing one set of standards is a daunting, if not impossible, task. For example, how does one write standards that govern MEMS devices used in both medical and automotive applications?

The solution seems to be common manufacturing standards and separate application standards. Semiconductor Equipment and Materials International (SEMI), the international standards group for the semiconductor manufacturing industry, has established a committee to draft MEMS manufacturing standards.

"We're looking at standards that have already been developed for the semiconductor industry that have a high degree of applicability to MEMS," explained Grace, a member of the SEMI committee. "Many of the processes in MEMS are similar to those in semiconductor manufacturing. The people designing MEMS need to know what those standards are."

The reason these standards don't already exist for an industry that's been around since the 1960s? Said Grace, "Standards are for mature industries. This is not a mature industry."

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Miniature Fuel Cells for Small, Portable Electronic Devices

A significant portion of the bulk and complexity of conventional fuel cells is eliminated.

NASA's Jet Propulsion Laboratory, Pasadena, California

Miniature fuel cells in a "flat-pack" configuration are being developed as alternatives to rechargeable batteries in cellular telephones, laptop computers, and other small, portable electronic devices. These fuel cells exploit the electrochemical oxidation of organic fuel (usually methanol) in air. Whereas power sources based on state-of-the-art lithium-ion batteries have specific energies of no more than ≈150 W·h/kg, power sources based on the present developmental fuel cells are expected to have specific energies between 500 and 1,000 W·h/kg. Moreover, whereas one must often wait for batteries to be recharged before using them, a fuel cell can be refueled and used immediately.

Conventional fuel-cell assemblies include bipolar plate stacks, pumps, blowers, and other ancillary items that not only contribute to cost but also add bulk and complexity, thereby posing considerable impediments to miniaturization. In the present developmental fuel cells, the flat-pack configuration is part of an overall improved design that eliminates much of the bulk and complexity.

A flat-pack fuel-cell assembly can include one or more fuel cells electrically connected in series and/or parallel to obtain the required current and/or voltage rating. A typical basic flat-pack fuel-cell assembly (see figure) contains a single polymer electrolyte membrane that serves multiple cells. The cathodes of all the cells are located side by side in the same plane on one side of the membrane, while the anodes of all the cells are similarly located on the other side of the membrane. A fuel-feed manifold and a wick deliver fuel in regulated amounts to the anodes. The cathodes are exposed to air in a manner similar to that of metal/air batteries.

Series electrical connections between adjacent cells are made in the form of posts that extend through the membrane. These posts are made from such corrosion-resistant, electronically conductive materials as graphite, platinum, and/or gold, along with (if needed) an appropriate stable polymeric binder. Alternatively or in addition, parallel and/or series electrical connections among cells can be made in the form of thin edge connector plates that include segmented strip conductors made of gold or graphite.

Fabrication of a multiple-cell membrane/electrode assembly like that shown in the figure involves the application, to the membrane, of catalyst layers and backing structures for the anodes and cathodes. The techniques of fabrication include the use of catalyst inks and either the use of pre-coated electrodes or else sputter deposition of the electrodes. Gas-diffusion backing layers are preferably bonded to the membrane by hot pressing. Optionally, nonbonded backing layers can be used instead of bonded ones.

The preferred anode catalyst is Pt-Ru; the preferred cathode catalyst is Pt. The anode structure is made hydrophilic so that an aqueous solution of liquid organic fuel can readily flow to the catalyst layer and the carbon dioxide product can readily leave the anode surface. The cathode is made hydrophobic to exclude water and thereby facilitate the flow of air.

This work was done by S. R. Narayanan, T. I. Valdez, Filiberto Clara, and Frank Harvey of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, access the Technical Support Package (TSP)* ***free online at www.nasatech.com/tsp*** *under the Electronic Components and Systems category.*

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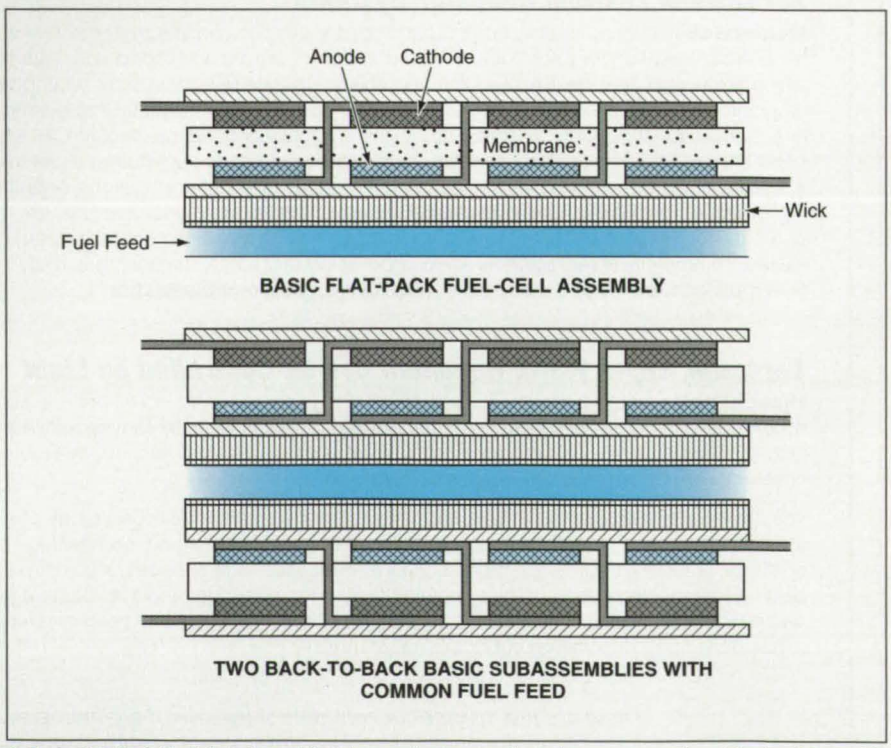
Refer to NPO-21066, volume and number of this NASA Tech Briefs *issue, and the page number.*



A **Basic Flat-Pack Fuel-Cell Assembly** takes up less space than does a conventional fuel-cell assembly of the same capacity. Multiple basic subassemblies can be combined in a compact back-to-back configuration to increase capacity.

"Morphing" in Evolutionary Synthesis of Electronic Circuits

The search for viable circuits can be conducted more efficiently and thus faster.

NASA's Jet Propulsion Laboratory, Pasadena, California

A method of automated evolutionary synthesis of electronic circuits has been augmented by a concept called "morphing through fuzzy topologies." Previous versions of the method provided for the evaluation of "crisp" topologies were precisely specified by open/closed (on/off) interconnection switches. The present, augmented version provides for evaluation of topologies specified by switches that support partial degrees of opening. These "fuzzy" topologies with partly open, partly closed switches have behaviors very similar to those obtained by a combination of "crisp" topologies. It is almost as if several "crisp" topologies are superimposed on each other, and are evaluated simultaneously when the fuzzy topology is evaluated. Like the previous versions, the present version is expected to enable the synthesis of a variety of digital and analog circuits with desired functional responses.

Previous, discrete-topology versions of the method were described in "Reconfigurable Arrays of Transistors for Evolvable Hardware" (NPO-20078), *NASA Tech Briefs*, Vol. 25, No. 2 (February 2001), page 36; and "Evolutionary Automated Synthesis of Electronic Circuits" (NPO-20535), *NASA Tech Briefs*, Vol. 26, No. 7 (July 2002), page 33. To recapitulate: "Evolution" is used here in a quasi-genetic sense, signifying the construction and testing of a sequence of populations of circuits that function as incrementally better solutions of a given design problem. The circuits are implemented either in software simulations or in hardware. Evolution in hardware involves the use of electronically reconfigurable arrays of transistors as analog switches for the selective, repetitive connection and disconnection of transistors and other circuit building blocks. The evolution is guided by a search-and-optimization algorithm (in particular, a genetic algorithm). At each step of the evolutionary process, the circuits are ranked according to how close their behaviors come to the desired behavior. A new population of circuits is generated from a selected pool of best circuits in the previous generation, subject to such genetic operators as chromosome crossover and mutation. The process is repeated for many generations, yielding progressively better circuits. The criterion for stopping the evolution can be the reduction of error below a certain threshold or reaching a predetermined number of generations.

The present, augmented method applies primarily to evolution in hardware and secondarily to software simulations in which highly accurate mathematical models of circuits are used. The hardware implementation would involve the use of field programmable transistor arrays (FPTAs), which contain T-gate transistors as analog switches. These switches differ from the switches of the discrete-topology version of the method in that instead of being limited to "on" or "off" states, their resistances would be continuously variable between low values (tens to hundreds of

ohms, in the "on" state) and high values (~ hundreds of MΩ in the "off" state).

By virtue of the intermediate values of the switch resistances, the response of a given circuit topology is almost as if one would combine the responses of several circuit topologies specified by on/off switches. The superposition of circuit topologies would be characterized as "fuzzy" because it would blur the borders among distinctive circuit topologies: the resulting circuits would belong, only to certain degrees, to discrete topologies, in each of which any two given components are either connected or not. In effect, a fuzzy topology would contain many "seeding" topologies with superimposed effects. The role of evolution would be, in part, to isolate the most promising one of the seeding topologies present. In still other words, evaluation of a fuzzy topology would be somehow equivalent to simultaneous concurrent evaluation of several superimposed circuit configurations.

The genetic algorithm would specify whether each switch would be in a low- or high-resistance state, but in a process somewhat reminiscent of annealing, the numerical meanings of "low" and "high" would change gradually as a function of a temperature-like parameter. Initially the temperature-like parameter would be high, causing the "low" and "high" switch status to have values close to each other. Gradually (typically over ≈100 generations to ensure quasi-static response), the temperature-like parameter would be made to decrease, causing the switch resistances to become polarized to their extreme high ("off") and low ("on) values. This annealing-like process would induce modifications of the circuit to be evolved. The evolutionary effect of this annealing-like process is what is meant by "morphing through fuzzy topologies."

Tests both in simulations and in hardware by computational simulation have led to the preliminary conclusion that in comparison with a discrete-topology version of the method implemented with binary switches, morphing through fuzzy topologies is about an order of magnitude more efficient as a means of searching for a desired circuit topology. Promising individuals (with higher fitness) have been found much earlier in the search.

If the goal in a given situation is to obtain a discrete topology, then morphing through fuzzy topologies can accelerate evolution toward the goal. On the other hand, in some cases, the degrees of opening of the switches could be regarded as extra degrees of freedom for design problems, thereby making possible increased numbers of solutions.

This work was done by Adrian Stoica and Carlos Salazar-Lazaro of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com/tsp*** *under the Electronic Components and Systems category.*

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Mixtrinsic Evolutionary Synthesis of Electronic Circuits

Designs are expected to be more robust and portable.

NASA's Jet Propulsion Laboratory, Pasadena, California

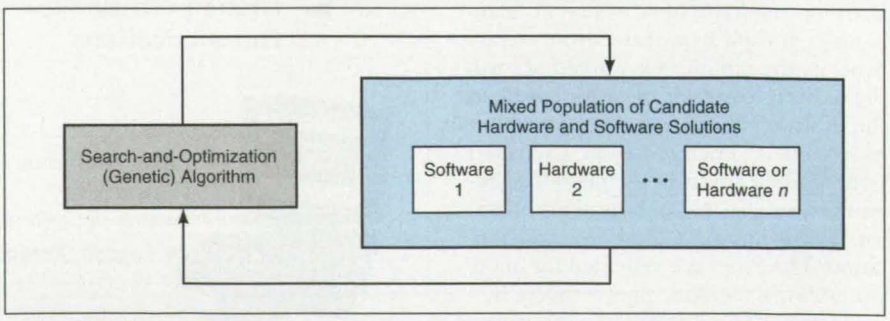
A method of automated synthesis of analog and/or digital electronic circuits involves evolution in both software simulations and hardware. Heretofore, the evolutionary automated synthesis of electronic circuits has been accomplished by use of either software simulations or hardware, but not both. Evolution in software has been called "extrinsic," while evolution in hardware has been called "intrinsic." Because evolution by the present method involves both intrinsic and extrinsic elements, it is called "mixtrinsic."

Part of the trouble with software evolution is that when some evolved circuits are implemented in hardware, their behaviors differ greatly from those predicted in the simulations. Similarly, part of the trouble with hardware evolution is that some circuits evolved in hardware behave differently when they are analyzed in computational simulations. The cause of these mismatches is the limited accuracy of the mathematical circuit models embodied in the software. To some extent, the accuracy of the circuit models can be increased at the cost of increased simulation time. However, some information about circuits depends on fabrication process and cannot be included in the models. In addition, it can be desirable to evolve circuits that exhibit behaviors independent of the details of fabrication processes.

Another important and related issue is that of robustness and portability of solutions. In each case, evolution finds the "easy way out," optimizing for whichever raw material (mathematical model or hardware components) is given. The inability to port a software solution to hardware renders the software solution useless in a commercial or other practical setting. On the other hand, the inability to analyze an evolved hardware solution in a software simulation reduces confidence in the hardware intrinsic solution because the solution cannot be shown to work outside the operating region used in the evaluations during evolution.

The limited range of applicability of a solution is of special concern if the solution exploits very specific effects. Such a solution could be characterized as a "point design." What is needed is a "domain-wide" design that could constitute a solution within a large envelope of operating parameters. Examples of such parameters include temperature, power-supply voltage, and measures of ionizing radiation.

In mixtrinsic evolution, one uses populations of mixed individuals — some



In **Mixtrinsic Evolution** for the automated synthesis of electronic circuits, mixed populations of both hardware and software are evaluated or each individual is evaluated both in hardware and in software.

evaluated in software simulations and some in real hardware (see figure). In a variation of the technique, each individual is evaluated both in hardware and in software and is assigned an averaged measure of goodness. Mixed populations constrain the evolution to a solution that both perform well in hardware and can be well simulated in software. Such a solution exploits characteristics included in the software model for producing the desired behavior but does not rely on the special characteristics of a specific hardware implementation. Solutions based on hardware properties outside the software model are eliminated by evolution, because during evolution, each solution can be randomly assigned for evaluation in either hardware or software. As a result, solutions are robust; in addition, they are likely to be patentable and in accordance with common design rules.

This work was done by Adrian Stoica of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com/tsp*** *under the Electronic Components and Systems category.*

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, NASA Management Office–JPL; (818) 354-7770. Refer to NPO-20773.

Sequential-Color LED Illumination for Reflective Microdisplays

Lyndon B. Johnson Space Center, Houston, Texas

Integrated silicon microdisplays, such as liquid-crystal-on-silicon (LCOS) devices, are becoming the most effective image source for high-resolution viewfinders, head-mounted displays, and helmet-mounted displays (HMDs). Since these microdisplays are reflective in nature, they require new arrangements of illumination and viewing optics compared to previous transmissive displays. A complete display might comprise a reflective microdisplay panel lit from the front, through a beam splitter, by a light-emitting-diode (LED) illuminator, and viewed through an eyepiece optic. Full-color display, without resolution-degrading color filter triads, can be achieved with one simple microdisplay panel by utilizing field-sequential color — easily attained by making the illuminator from a few red, green, and blue LEDs. The best image quality is provided, though, when the illuminator appears as an extended diffuse white spot, rather than red, green, and blue points. This can be achieved by spacing a diffuser between the LEDs and the display, with the light from the differently colored LEDs overlapping on the diffuser to make a white spot. An especially efficient arrangement is achieved with a specularly reflecting microdisplay when the illuminator and eyepiece lens are positioned so that the lens simultaneously makes a virtual image of the display panel, and a real image of the illuminator. By arranging the image of the illumi-

nator to fall in the same position as the pupil of the viewer's eye, the largest possible amount of illumination light is made usable by the viewer, while the amount wasted is minimized. For microdisplays that operate in polarized light, high optical efficiencies are obtained if the needed beam splitter is a polarizing beam splitter (PBS). The overall system can be simplified if the PBS is curved, which saves space and combines the function of an illuminator condenser or collimating lens. PBS function can also be obtained from suitable edge-illuminated holographic illuminators.

This work was done by Mark Handschy, Mike Meadows, and Holden Chase of Displaytech, Inc., for **Johnson Space Center**.

In accordance with Public Law 96-517, the contractor has elected to retain title to this invention. Inquiries concerning rights for its commercial use should be addressed to

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Refer to MSC-22990/91, volume and number of this NASA Tech Briefs *issue, and the page number.*

Multifunction Input/Output Integrated Circuits

Advantages would include network fault tolerance and simplification of wiring.

NASA's Jet Propulsion Laboratory, Pasadena, California

Integrated circuits that would perform a variety of analog-signal, digital-signal, and power input/output functions have been proposed. Conceived for use as versatile, fault-tolerant interfaces among components and subsystems of spacecraft, these multifunction integrated circuits could also be attractive for similar uses in a variety of terrestrial systems, including ground vehicles, aircraft, industrial facilities, and communication systems.

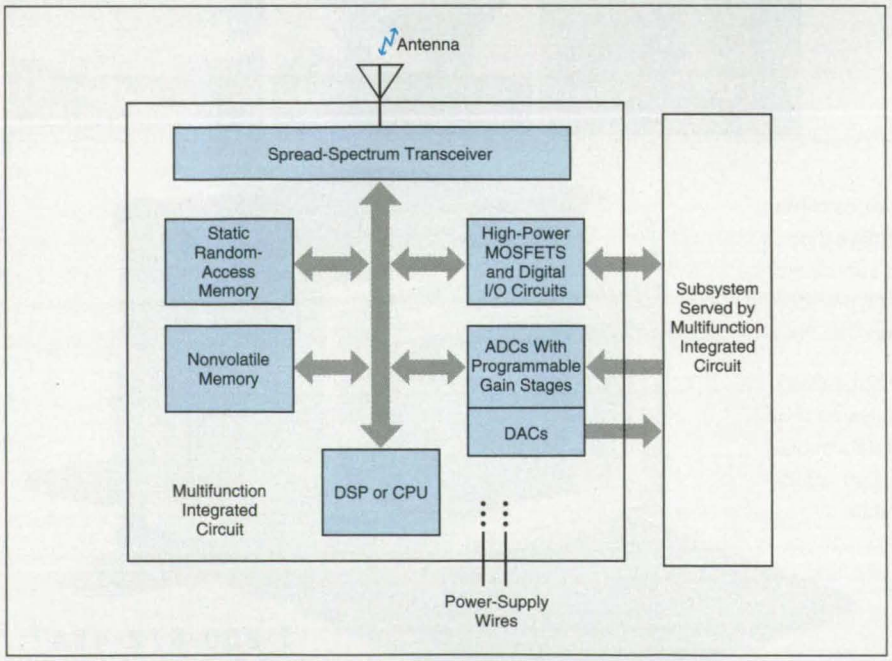
Each such multifunction integrated circuit would be fabricated as a single complementary metal oxide semiconductor (CMOS) chip that would contain some or all of the following functional units (see figure):

- A transceiver for spread-spectrum radio communication with other such integrated circuits;
- A microprocessor functioning as a central processing unit (CPU) or digital signal processor (DSP);
- Volatile and/or nonvolatile memory circuits;
- Analog input circuits, including signal-conditioning amplifiers and analog-to-digital converters (ADCs);
- Analog output circuits, including digital-to-analog converters (DACs);
- Digital input/output (I/O) circuits;
- Power-switching circuits containing high-power metal oxide semiconductor field-effect transistors (MOSFETs).

The multifunction integrated circuit would serve as both a power and a signal interface for the subsystem or component to which it was connected. If, for example, the subsystem were a motor, then the multifunction integrated circuit could receive motor commands transmitted by radio from a different subsystem, switch the motor power on and off as needed, and possibly transmit data on the operation of the motor (e.g., shaft-angle, speed, voltage, and/or current readings) to another subsystem. Other than wire connections for a radio-communication antenna and for the motor or other subsystem served, the only wire connections between the multifunction integrated circuit and the rest of the system would be those needed to supply power to the circuit and subsystem.

All data and control signals — both digital and analog — would be transmitted via the radio links. By serving as standardized interfaces that would eliminate the need for signal wiring, these multifunction integrated circuits could make it easier to design and construct multinode systems that could be reconfigured in software (and perhaps in hardware). With respect to digital communication among subsystems, each of the multifunction integrated circuits would constitute a node of a wireless communication network. By use of previously developed Ethernet (or equivalent) and spread-spectrum protocols, babbling (uncontrolled transmission) by one of the nodes of the network would be prevented from interfering with communication among the other nodes.

This work was done by James Dillon and Michael Newell of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com/tsp*** *under the Electronic Components and Systems category. NPO-30212*



This **Interface Circuit** would contain a variety of analog and digital circuitry, all integrated on a single chip, for performing a complete set of signal and power input and output functions for the subsystem to which it would be connected.

SEU-Tolerant Flip-Flops

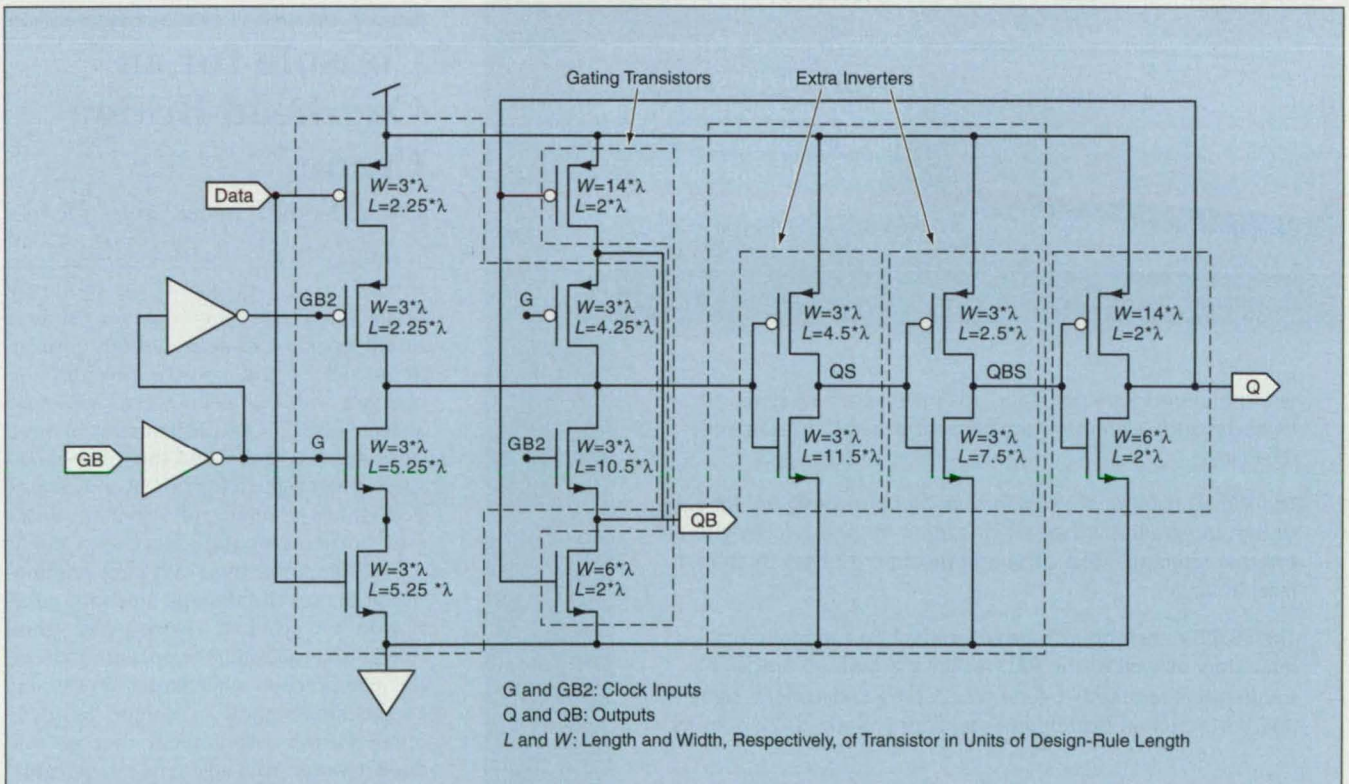
These circuits could be fabricated on commercial CMOS process lines.

Lyndon B. Johnson Space Center, Houston, Texas

Several improvements in the designs of flip-flop circuits that are parts of logic circuits have been proposed to reduce the incidence of logic errors associated with single-event upsets (SEUs) [bit flips caused by incident energetic ionizing particles]. Traditionally, radiation-hardened integrated circuits have been manufactured on special process lines, with emphasis, variously, on immunity to latchups and SEUs for outer-space applications or on total-dose hardness for military applications. The present improvements are intended to confer latchup and SEU immunity of a degree and type suitable for outer-space applications, but unlike in the traditional approach, the improved designs could be implemented on ordinary commercial complementary metal oxide semiconductor (CMOS) process lines.

A complete description of the proposed improvements and of the historical background prerequisite to understanding the improvements would greatly exceed the space available for this article; only a brief summary can be given here. Historically, guard rings have been used to prevent latchups. In theory, SEU can be eliminated via redundancy, but conventional redundancy involves at least 3 copies of all basic logic circuitry plus additional logic circuitry in the form of an infallible voter circuit. One patented scheme calls for dual redundant flip-flop circuits, called "Whitaker cells" after their inventor, in which what is known about the possible directions of upsets in n- and p-channel devices is utilized to enable the cells to recover from upsets. Numerous other prior developments involve using extra delays within the flip-flop to reduce its susceptibility to glitches. These include the addition of passive components, which are often expensive to fabricate in a logic process, or extra pairs of inverter stages. The minimum number of extra inverter stages described in prior art is 2 pair, or 4 extra inverters. There are also other non-Whitaker schemes involving dual flip-flops cross-coupled in some novel way to avoid or reduce upset.

In the dual flip-flop schemes, dual rail logic may be used to drive the pair of flip-flops. In the Whitaker scheme, single rail logic may also be used, with the second flip-flop data provided through a delay equal to the worst-case glitch time for the logic family, which eliminates the possibility of a glitch arriving simultaneously on both flip-flops. The worst-case time is approximately the propagation time for a fully loaded node on the slowest gate. All gates must be designed with balanced rise and fall times for this to work. Glitches on



This **Compact SEU-Immune Flip-Flop Circuit** would be almost completely immune to SEU. The two extra inverters together with the normal gating transistors provide three independent delay stages for absorbing glitches, the minimum theoretically required. Glitches are absorbed whether generated internally, or whether coming in on the Data or clock (GB) lines, as long as the timing guidelines are followed. What is shown is a latch, which is 1/2 of the common D-flip-flop circuit.

clock lines must be avoided either by distributing clock signals separately to the two sides of the dual flip-flop, or using extra capacitances (up to 4 pF) and large drivers on all clock lines, and avoiding the generation of a clock line internally. These are very restrictive and expensive constraints. Nor do these prior developments provide for asynchronous preset and clear operations.

The proposed improvements are summarized as follows:

- Optimized transistor sizing is used to make the shortest possible delay elements in a delay-based design, without resorting to passive components or more than one extra pair of inverters within the flip-flop. This requires fewer transistors than prior delay-based designs, and far fewer than any of the dual flip-flop designs.
- Some of the delay is distributed into existing transistors within the flip-flop in order to control the glitch times which can be generated within the flip-flop, while absorbing external data or clock line glitches.
- The same delay-based technique would be used to enable asynchronous preset and clear.
- Only one guard ring with allowed polycrystalline-silicon crossings would be used.
- Multistage balanced rise and fall times inside an ordinary flip-flop would be used to absorb glitches without changing state of the flip-flop.

Circuits that incorporate the proposed improvements could be simpler, more compact, and more functional, relative to prior SEU-immune circuits based on dual flip-flops or more costly delays. The delays involved, approximately one to two gate delay times in operation of the flip-flop, are comparable or less than the delays introduced in all prior forms of radiation-tolerant flip-flops (except the expensive and complicated case of dual flip-flops driven by dual-rail logic).

This work was done by Robert Shuler, Jr., of **Johnson Space Center**.

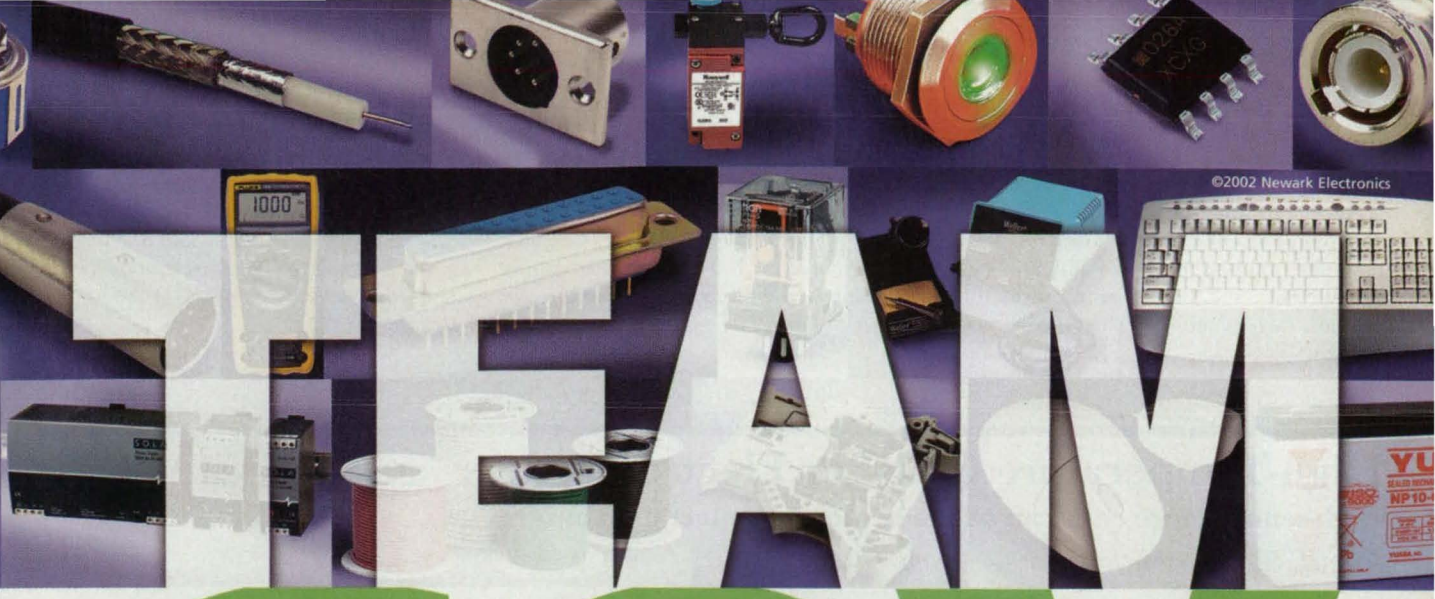
This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Johnson Space Center, (281) 483-0837.

Refer to MSC-22953.

Console for an Overhead-Bridge Crane

John F. Kennedy Space Center, Florida

Human factors engineering has been applied to the design of an overhead-bridge crane control console for use by a seated operator in a clean-room environment. The crane console provides the operator with the ability to lift and move loads up to 27.5 tons (24.9 tonnes) in three vertical speed ranges and three horizontal speed ranges with a horizontal and vertical positioning accuracy of 0.010 in. (0.25 mm) and 0.005 in. (0.13 mm), respectively. The design, to be used with radio communication, provides the operator with information on position, velocity, and crane functioning, allowing the operator to move the load precisely while having no visibility of the crane hook (a unique Kennedy Space Center requirement that necessitated a wavier from a Federal safety regulation). The console dimensions and seating provide adjustability to accommodate 90 percent of the population and minimize the risk factors associated with fatigue and



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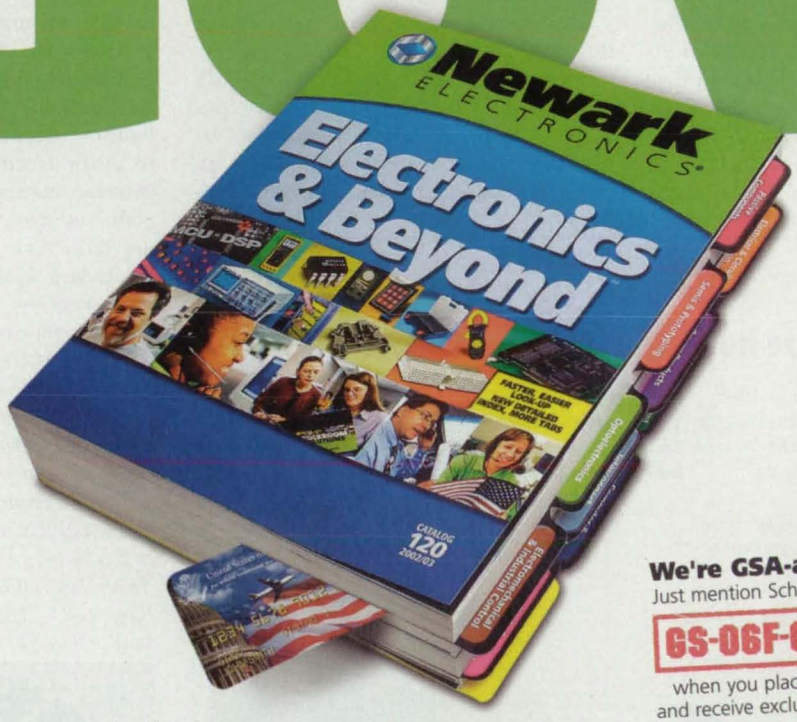

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cumulative trauma disorders. The controls and displays were selected to optimize human performance. They were arranged according to functional groups, sequence, and frequency of expected use and positioned to optimize reach, visibility, and legibility. The systematic application of human factors engineering principles throughout the design process will reduce the probability of human error during operations and maintenance, thereby increasing overall safety in crane operations.

This work was done by Faith T. Chandler and William D. Valentino of The Boeing Company for **Kennedy Space Center**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com/tsp*** *under the Electronic Components and Systems category.*

Inquiries concerning rights for the commercial use of this invention should be addressed to the Technology Commercialization Office, Kennedy Space Center, (321) 867-8130. Refer to KSC-12279.

High-Temperature Coils for Electromagnets

High-temperature coils can be made more compact than before.

John H. Glenn Research Center, Cleveland, Ohio

Coiled electric wires have been developed for use in electromagnets that operate at high temperatures. Examples of such electromagnets could include the actuators in magnetic bearings in advanced gas turbines.

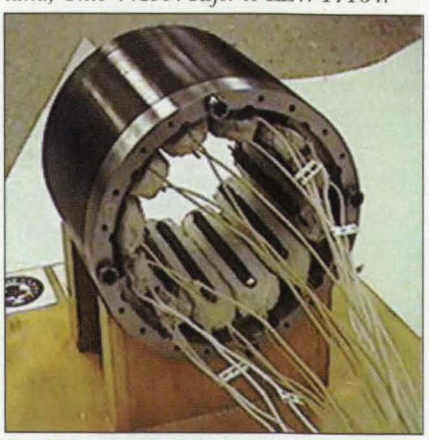
The primary distinction between these wires and previously commercially available high-temperature wires lies in the electrical insulation, which is intended to withstand operating temperatures in the range from 800 to 1,300 °F (≈430 to ≈700 °C). The commercially available wires feature tubular sheaths filled with insulating materials; while such insulation is effective, it is too bulky for electric-coil applications in which there are stringent limitations on the sizes of the coils and/or on the spacing between turns. The present wires feature improved insulation that is thinner, making it possible to fabricate coils that are smaller and more closely wound.

The starting wire material for a coil of this type can be either a nickel-clad, ceramic-insulated copper wire or a bare silver wire. The starting wire is either primarily wrapped with S-glass as an insulating material or else covered with another insulating material wrapped in S-glass prior to the winding process. A ceramic binding agent is applied as a slurry during the winding process to provide further insulating capability. The turns are pre-bent during winding to prevent damage to the insulation. The coil is then heated to convert the binder into ceramic.

In a test, coils of this type were mounted in a 12-pole magnetic bearing (see figure) and found to perform successfully at temperatures up to 1,200 °F (≈650 °C). Future development efforts will address the problems of increasing the thermal conductivity of the electrical-insulation materials to increase conduction of heat out of the coils, reducing the volumes of the coils, and fabrication of coils with various shapes (including square and other noncircular cross sections).

This work was done by Alan Palazzolo of Texas A&M University for **Glenn Research Center**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com/tsp*** *under the Electronic Components and Systems category.*

Inquiries concerning rights for the commercial use of this invention should be addressed to NASA Glenn Research Center, Commercial Technology Office, Attn: Steve Fedor, Mail Stop 4–8, 21000 Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-17164.



The **Connection End of a 12-Pole Magnetic Bearing** is depicted here during a test at a temperature of 1,000 °F (≈540 °C) in a series of tests that ranged up to 1,200 °F (≈650 °C).

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Software

Software Generates Sequences of Operations for a Mars Rover

Automated Rover Sequence Generation (ARSG) is a prototype computer program for ground-based automatic generation of sequences of commands that can be used for a robotic exploratory vehicle (rover) on Mars. ARSG is based on the Automated Scheduling and Planning Environment (ASPEN) computer program, which has been described in several *NASA Tech Briefs* articles in recent years. Given high-level scientific and engineering activities required of a rover, ARSG automatically generates a sequence of commands that can be executed by the rover within resource constraints and in compliance with flight rules. An automated-planning-and-scheduling software subsystem encodes rover design knowledge and uses search and reasoning techniques to automatically generate low-level command sequences while (1) respecting rover operability constraints, scientific and engineering preferences, environmental predictions, and (2) adhering to hard temporal constraints. By enabling goal-driven command of planetary rovers, this software can reduce the need for highly skilled rover engineering personnel, thereby reducing the costs of mission operations. ARSG enables faster responses to changes in the state of a rover (e.g., malfunctions) or to scientific discoveries by eliminating the time-consuming manual validation of command sequences and enabling rapid "what-if" analyses.

Contributors to this software include Robert Sherwood, Tara Estlin, Darren Mutz, Gregg Rabideau, Steve Chien, Paul Backes, Jeff Norris, Brian Cooper, and Scott Maxwell of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com/tsp*** *under the Software category.*

This software is available for commercial licensing. Please contact Don Hart of the California Institute of Technology at (818) 393-3425. Refer to NPO-30204.

Web-Based Software Service Improves Space-Shuttle Processing

Human data-transfer from space-shuttle checkout systems to shuttle business systems is slow, error-prone, and expensive. The Operations and Maintenance Requirement Specification-Automated Buy Off System (OMRS-ABOS) is a software system that automatically transfers test-validation data produced by Kennedy Space Center's Checkout and Launch Control System (KSC's CLCS) for the space shuttle, to its Integrated Work Control System (IWCS). The test-validation data includes pass/fail results from equipment tests required by a set OMRSs. While other commercial-off-the-shelf (COTS) approaches require existing work forces to change their business practices, OMRS-ABOS utilized a COTS approach that preserved KSC business practices. The OMRS-ABOS implemented commercial Enterprise Application Integration (EAI) software development practices, deployed to an *n*-tier software architecture, and utilized Java 2 Enterprise Edition (J2EE). The COTS software platform saved time and expenses while infusing state-of-the-industry technologies. OMRS-ABOS provides a channel for KSC enterprise shuttle checkout systems to transfer OMRS events to IWCS. The Remote Manipulator System (RMS) Checkout System is the latest to automate its transfer of OMRS-event data. OMRS-ABOS' latest improvement includes distributed data communications made available by the eXtensible Markup Language (XML). By utilizing XML as a data transport vehicle, OMRS-ABOS may communicate more easily with commercial enterprise platforms.

This work was done by Todd Flato, Keith Heob, and Barry Rubel of Riptide Software Incorporated and Kevin Smith of **Kennedy Space Center**.

This technology is available for commercial licensing. Please contact Barry Rubel of Riptide Software Incorporated at (321) 427-5694. Refer to KSC-12312.

Program Analyzes Current Signatures of Solenoid Valves

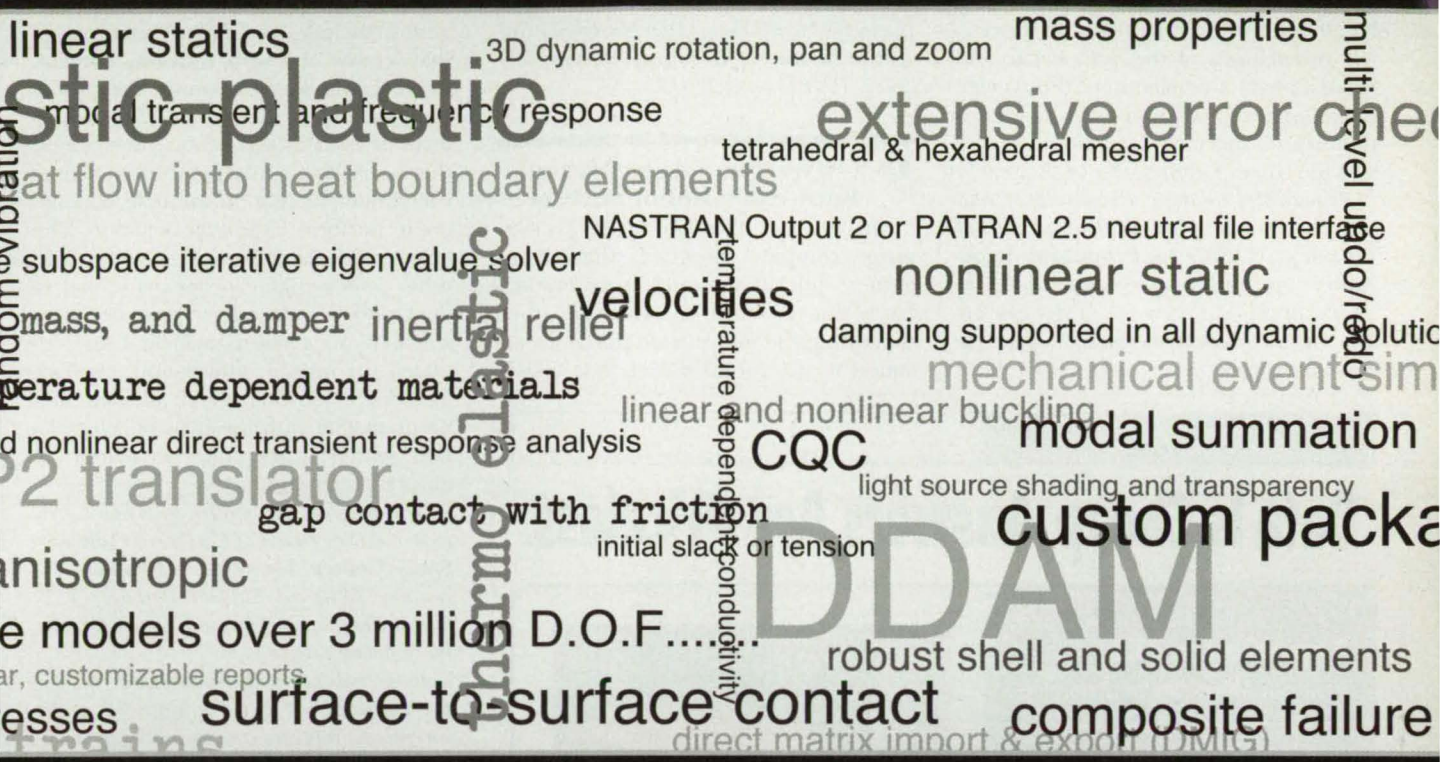
A computer program processes signal data in the instrument described in "Current-Signature Sensor for Diagnosing Solenoid Valves" (KSC-12152), *NASA Tech Briefs*, Vol. 25, No. 9 (September 2001), page 30. Ten-bit samples of the electric current in a solenoid valve are acquired at a rate of 10 kHz and fed to a digital signal processor that executes the present software, which performs buffering, filtering, identification of features, and general assessment of the "health" of the valve. The identified signal features include the time of beginning of a transition, the time of maximum change in current, the time when the poppet begins to move, the amplitude of the current needed to initiate movement, the time of travel of the poppet to final seating, the time when the current reaches the steady state, the amplitude of the steady-state current, the minimum current needed to hold the poppet against unseating, and the time required for the poppet to unseat. The software can generate indications of impediment or jamming of the poppet; burnt or short-circuited solenoid windings; buildup of friction; faulty valve spring; incorrect operating voltage, temperature, or pressure; bounce during seating of the poppet; and failure of anti-arcing circuitry.

This program was written by Bradley M. Burns of Dynacs, Inc., for **Kennedy Space Center**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com/tsp*** *under the Software category.*
KSC-12220

Program Predicts Radiation Forces on a Satellite

A computer program predicts the radiation forces on the TOPEX/Poseidon satellite at any point in its orbit around the Earth. The program performs a unified analysis of the thermal, radiative, power-generation, and orbital-mechanics aspects of operation because these aspects are interdependent: The power-generating capacity of the solar panel of the satellite depends on both the impinging radiation and its temperature, which, in turn depends on both its power output and the radiative environment. The radiative environment depends on the trajectory and attitude of the satellite relative to the positions of the Earth and Sun. Only by considering all of the aforementioned phenomena together can one predict the temperature and power generation of the solar panel and the battery charges, currents, and voltages. Then the radiation forces are calculated from the results of the foregoing unified thermal/power/radiative analysis. Output is available in two forms: (1) a tabulation of all components

Q. Why is full featured FEA so expensive?



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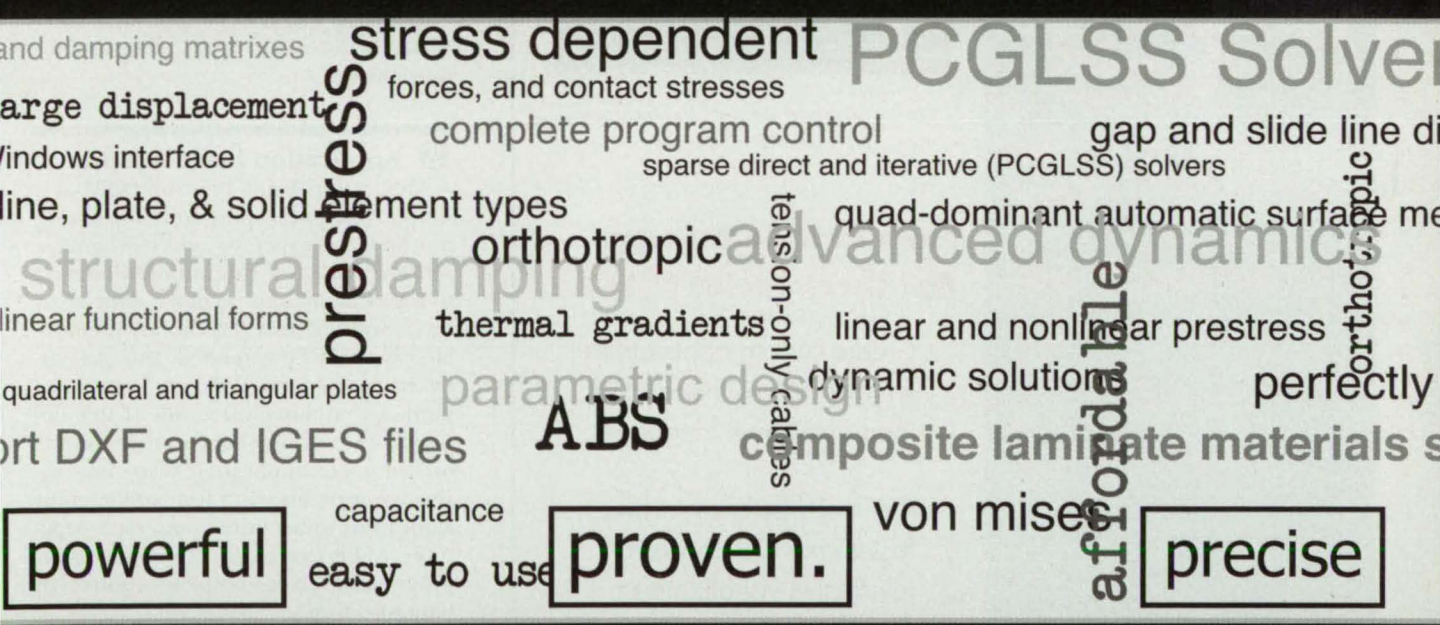

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of radiative forces over a single orbit, based on the day of the year and the relative orientations of the Sun, Earth, and orbit; and (2) a tabulation of the average radiation forces over a single orbit for any number of specified beta prime angles and the corresponding days of the year.

The unified analysis was developed and this program was written by Robert Richter of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com/tsp*** *under the Software category.*

This software is available for commercial licensing. Please contact Don Hart of the California Institute of Technology at (818) 393-3425. Refer to NPO-21019.

OwWwL and AgentNation: Knowledge-Robot Software

OwWwL and AgentNation are Java-language computer programs that act together, quickly scanning Internet databases for relevant information, then organizing the information into a format suited to the user. OwWwL is a search-engine program that, like other such programs, includes a "spider" subprogram that "crawls" the Web, indexing content. AgentNation is a collaborative-computing program that is used by OwWwL to perform its tasks in a collaborative manner; that is, OwWwL and AgentNation can be run simultaneously on multiple computers to perform large-scale searches. The biggest difference between OwWwL and other search-engine programs is that as the OwWwL spider subprogram performs a search on a given topic, it begins to search for related information. OwWwL includes a personal-search-assistant subprogram that with the help of AgentNation, searches other Internet search engines simultaneously.

This program was written by Joseph L. Nieten and Dan Dexter of LinCom for **Johnson Space Center**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com/tsp*** *under the Software category.*

In accordance with Public Law 96-517, the contractor has elected to retain title to this invention. Inquiries concerning rights for its commercial use should be addressed to

LinCom
1020 Bay Area Blvd.
Suite 200
Houston, TX 77058

Refer to MSC-23063, volume and number of this NASA Tech Briefs *issue, and the page number.*

Application Fault Injector

Application Fault Injector (AFI) is a simple computer program for testing the fault tolerance of other programs. AFI is a library of subroutines designed to inject faults into memory, data structures, and registers. The library is modular, can easily be extended, and can easily be ported to different computer hardware architectures. AFI is not designed to run fault-injection campaigns on complete application programs: instead, it is designed to test fault-tolerant algorithms, subroutines, and data structures. AFI is easy to use. The application programmer has complete control of fault injection.

This program was written by Thomas Wolfe of Caltech for **NASA's Jet Propulsion Laboratory**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com/tsp*** *under the Software category.*

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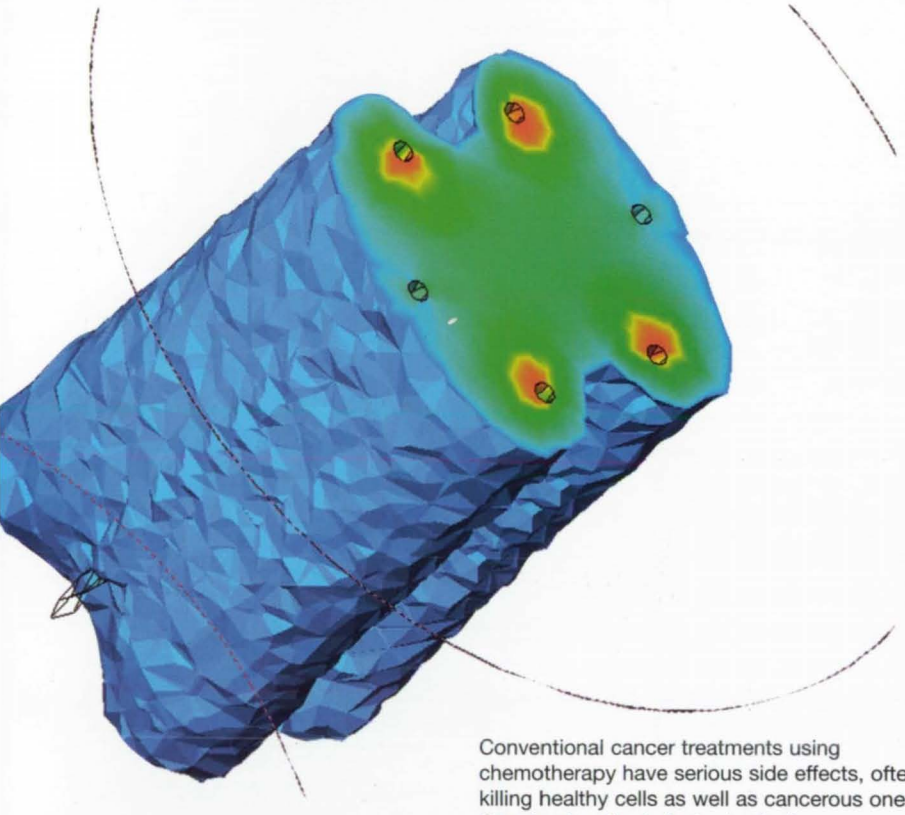

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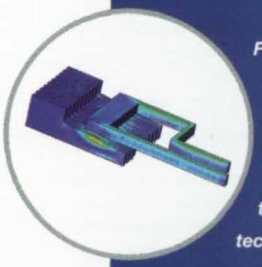

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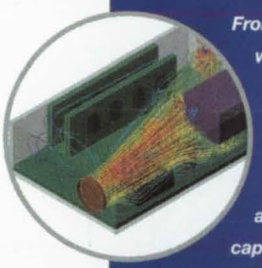

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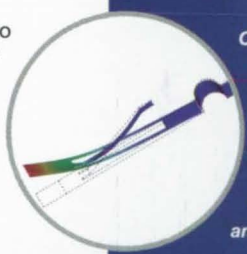

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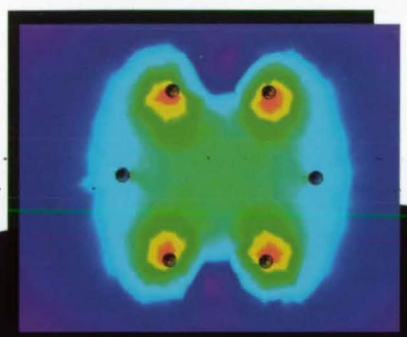
Conventional cancer treatments using chemotherapy have serious side effects, often killing healthy cells as well as cancerous ones. Genetronics, the industry leader in electroporation therapy, uses COSMOS/EMS to design and develop cutting edge electrodes for use in a new, electroporation therapy for cancer patients. Their patented electroporation technology could some day provide targeted cancer and gene therapy treatment for patients around the world.



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O ❑ Automotive
T ❑ Transportation
M ❑ Materials/Chemicals
P ❑ Power/Energy
B ❑ Bio/Medical
J ❑ Consumer Product Manufacturing
Q ❑ Industrial Machinery & Equip.
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G ❑ Government
D ❑ Defense
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Z ❑ Other *(specify)*: _____

3 **Your engineering responsibility is:** *(check one)*

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B ❑ Manage a Project Team
C ❑ Manage a Project
D ❑ Member of a Project Team
E ❑ Other *(specify)* _____

4 **Your job functions are:** *(please check all that apply)*

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12 ❑ Testing & Quality Control
13 ❑ Manufacturing & Production
14 ❑ Engineering Management
16 ❑ General & Corporate Management
17 ❑ Basic R&D
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Write in the number of your principal job function _____

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04 ❑ Software
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34 ❑ Power supplies & batteries
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06 ❑ Workstations
36 ❑ EDA/CAE software
37 ❑ CAD/CAM software
17 ❑ Imaging/video/cameras
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39 ❑ Optics/optical components
40 ❑ Fiber optics
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30 ❑ Fluid power and fluid handling devices
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42 ❑ Rapid prototyping and tooling
13 ❑ Metals
28 ❑ Plastics & ceramics
27 ❑ Composites
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Reducing Wear and Friction of CVD Diamond Films

Surface modifications reduce friction and wear, even in ultrahigh vacuum.

John H. Glenn Research Center, Cleveland, Ohio

Progress has been achieved in continuing research directed toward increasing the wear resistance and enhancing the self-lubrication properties of chemical-vapor-deposited (CVD) diamond films. Such films are potentially useful as friction- and wear-reducing coats on sliding mechanical components (e.g., seals, gears, and journal bearings). A major issue that has been addressed in this research is the variation of the friction and wear properties of CVD diamond with environment: In air, CVD diamond exhibits a low coefficient of friction and high resistance to wear; in vacuum, it exhibits a high coefficient of friction and low resistance to wear. In three experimental studies, it was found that friction and wear of CVD diamond films in both vacuum and air can be reduced by use of suitable surface treatments.

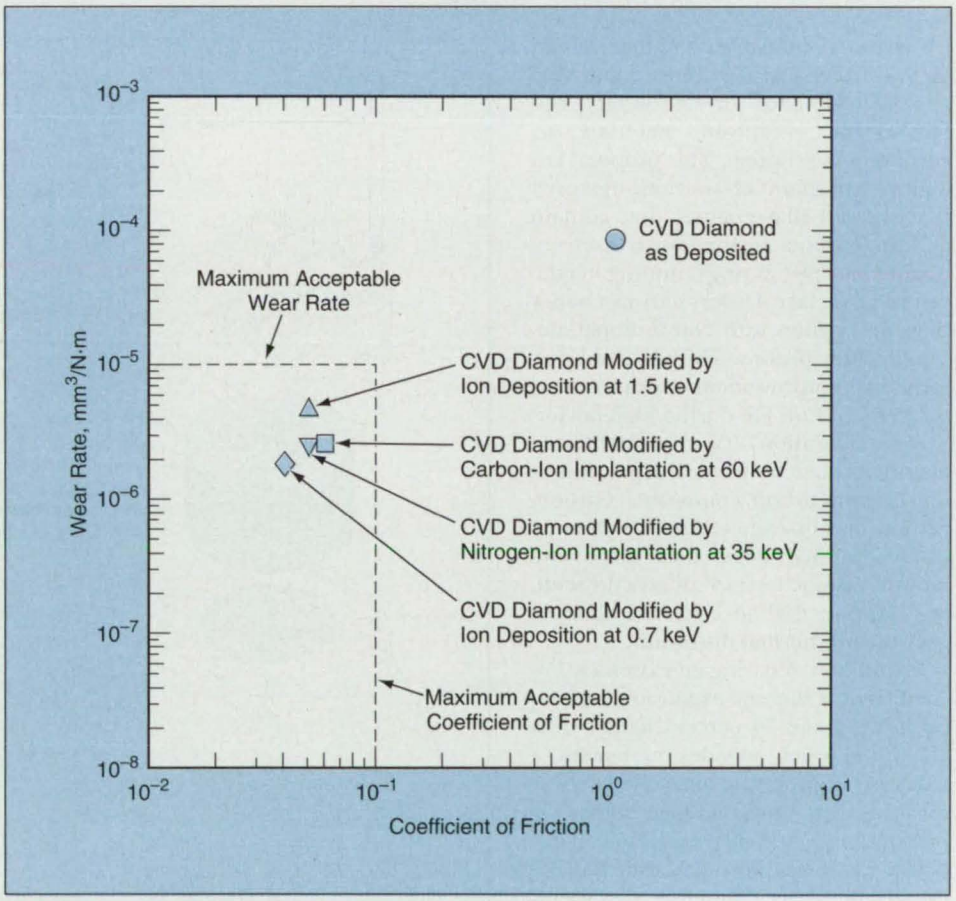
In the first study, a fine-grained CVD diamond film in the as-deposited condition was tested in comparison with two similar CVD diamond films that were coated with thin (< 1 μm thick) films of amorphous, non-diamond carbon [more specifically, hydrogenated carbon, also known as diamond-like carbon (DLC)]. The DLC coating layers were deposited by direct impacts of ion beams at kinetic energies of 1.5 keV and 0.7 keV, respectively. In tribological tests (diamond-tipped pins sliding on disks coated with the various CVD diamond films) at room temperature in ultrahigh vacuum, the DLC films were found to reduce the coefficient of friction and the wear rate significantly (see figure).

The second study was similar to the first study. Fine-grained CVD diamond films were modified by implantation of, variously, carbon ions at a kinetic energy of 60 keV or nitrogen ions at a kinetic energy of 35 keV. In both cases, the implantation resulted in the formation of amorphous, non-diamond carbon surface layers <1 μm thick. As in the first study, the modification of the as-deposited CVD diamond reduced the coefficient of friction and the wear rate significantly.

The subject matter of the first and second studies overlaps with that of a prior study reported in "Ion-Beam-Deposited DLC Coatings on Fine-Grain CVD Diamond" (LEW-16564), *NASA Tech Briefs*, Vol. 22, No. 7 (July 1998), page 62. The third study addressed the issue of a friction- and wear-resistant couple of materials; that is, a pair of materials that exhibit low friction and low wear when slid against each other. This study included ultrahigh-vacuum tests in which CVD-diamond-tipped pins were slid against a disk coated with cubic boron nitride films. The wear rate of the boron nitride films was found to be acceptably low (of the order of 10^{-6} $mm^3/N{\cdot}m$), the wear rate of the diamond films was found to be much lower, and the coefficient of friction was found to be very low (of the order of 0.02).

This work was done by Kazuhisa Miyoshi of **Glenn Research Center**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com/tsp*** *under the Materials category.*

Inquiries concerning rights for the commercial use of this invention should be addressed to NASA Glenn Research Center, Commercial Technology Office, Attn: Steve Fedor, Mail Stop 4–8, 21000 Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-17150.



Wear Rates and Coefficients of Friction of as-deposited and modified CVD diamond films were measured in ultrahigh vacuum. The results plotted here indicate that suitably modified CVD diamond films could be useful as wear-resistant, self-lubricating surface layers on sliding mechanical components.

Water-Jet Accelerator for Launching a Spacecraft

John F. Kennedy Space Center, Florida

A proposed ground-based apparatus would accelerate a spacecraft to speed of about mach 1, thus making it possible to increase the payload and/or reduce the cost of launching the spacecraft into orbit. The apparatus would include a track along which the spacecraft would ride on a sled. Hundreds of small water jets energized by compressed-air packs would be located under, and at small intervals along, the track. Each jet would be activated in turn as the sled passed by, aiming a high-speed (possibly supersonic) stream of water at baffles on the underside of the sled. The force of water impinging on the baffles would provide levitation and accelerate the sled along the track. Unlike a previously proposed launch-assisting linear electric motor, the water-jet apparatus would function without need for expensive electric-power-conditioning equipment. Unlike another launch-assist concept involving a piston driven along a pneumatic tube, the present concept does not present problems of how to (1) couple the piston to the sled and (2) exert fine control over acceleration. Another advantage of the water-jet concept is redundancy: even if several water jets were to malfunction, the remaining many functional water jets should suffice.

This work was done by Robert Youngquist and Frederick Adams of **Kennedy Space Center**. *For more information, contact the Kennedy Commercial Technology Office at 321-867-8130. KSC-12257*

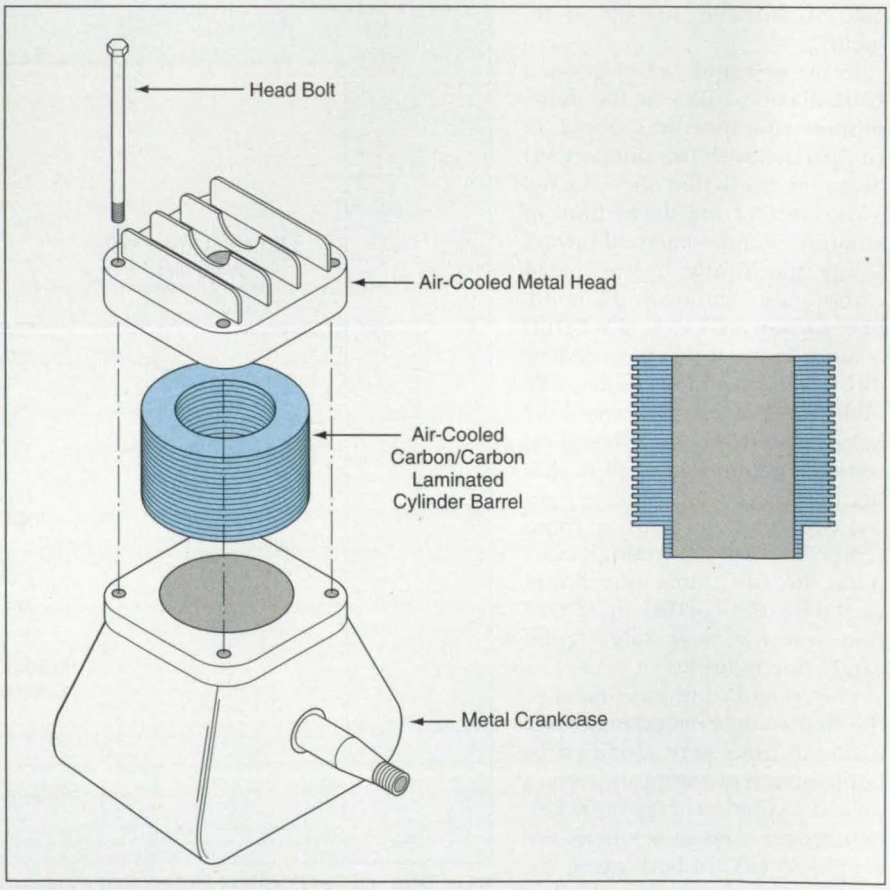
Internal-Combustion Engines With Ringless Carbon Pistons

Efficiencies would be higher and weights lower than those of conventional engines.

Langley Research Center, Hampton, Virginia

Internal-combustion engines would be constructed with cylinders and ringless pistons made of lightweight carbon/carbon composite materials, according to a proposal. This proposal is a logical extension of previous research that showed that engines that contain carbon/carbon pistons with conventional metal piston rings running in conventional metal cylinders perform better than do engines with conventional aluminum-alloy pistons. The observed performance improvement (measured as increased piston life during high-performance operation) can be attributed mainly to the low thermal expansion of the carbon-carbon composite. Carbon-carbon pistons can continue to operate under thermal loads that cause aluminum pistons to seize or sustain scuffing damage due to excessive thermal growth and thermal distortion.

In addition to having an extremely low coefficient of thermal expansion, carbon-carbon is about 30 percent lighter than aluminum which provides the benefit of reduced reciprocating mass (lower reciprocating mass can potentially reduce vibration forces and increase r/min. capability). Carbon-carbon composite also has the advantage over aluminum that it fully retains room-temperature strength and stiffness at high temperatures. Further-



The **Carbon/Carbon Laminated Cylinder Barrel** in this single-piston engine (or the carbon/carbon laminated cylinder block in a multiple-piston engine) would house a ringless carbon/carbon piston.

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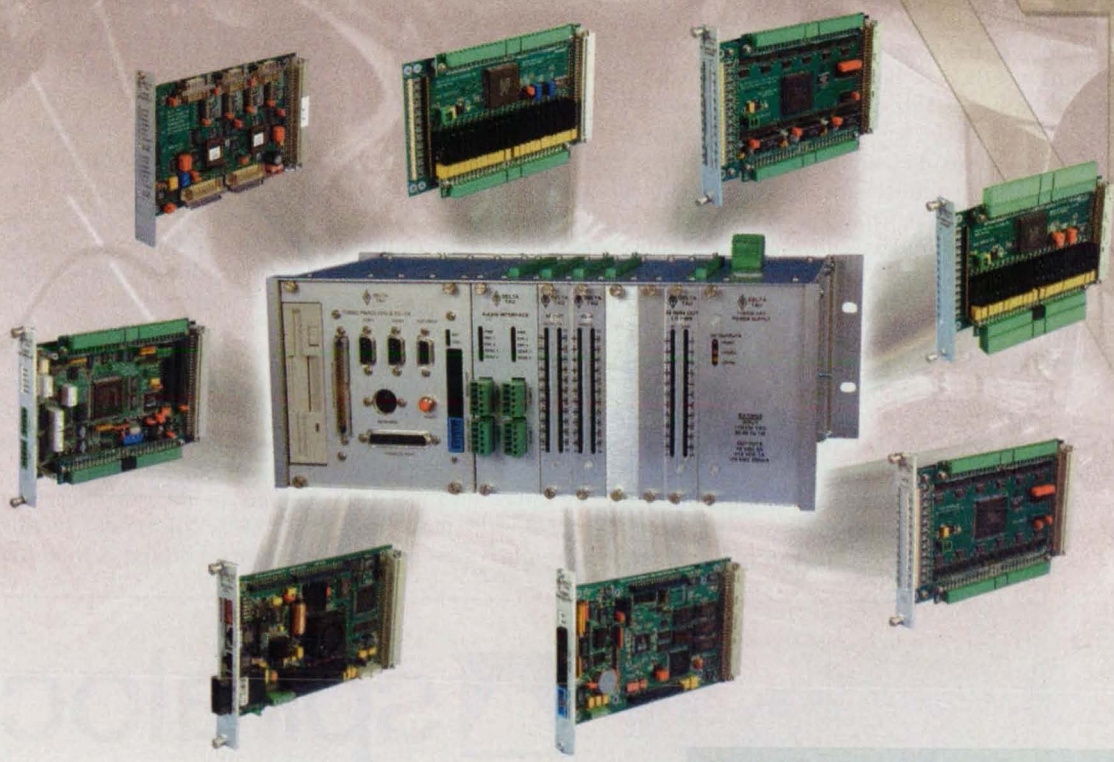

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more, the strength, thermal expansion, and thermal conductivity of carbon-carbon composites can be tailored by orientation of the carbon fibers and selection of fiber type, matrix type, and processing methods.

The rings are needed on aluminum pistons to seal the clearance which must exist between the piston and cylinder wall to accommodate differential thermal expansions of the piston and cylinder material (conventionally, a cast iron sleeve in an aluminum block). Although cold-clearance can be reduced somewhat by substituting a carbon-carbon piston, rings will still be needed to obtain effective sealing. An advantage is potentially achievable in a four-stroke engine because a tighter piston fit reduces the so-called "crevice volume" or the gap between the piston and the cylinder wall above the top ring. Fuel mixture which enters this gap is not combusted and is exhausted as unburned hydrocarbon. If the metal block were to be fitted with a carbon-carbon sleeve, the cold clearance could be further reduced, but minimum clearance might be difficult to achieve because the sleeve shape could be affected by thermally-induced distortions in the surrounding metal block (there are also issues as to how the sleeve might be contained in the block). If, on the other hand, the metal cylinder block and sleeve were to be replaced with a cylinder block made entirely of carbon-carbon, the thermal expansion differential between the piston and cylinder materials would virtually be eliminated, as would the potential for thermal distortion of either component. The clearance could then be reduced to the absolute minimum. Operation without rings, which would eliminate a source of power-robbing friction, can now be considered an intriguing possibility. Rings may ultimately be required in the four-stroke application to minimize combustion-gas blow-by and/or control oil consumption; however, the crevice volume, which is a major cause of hydrocarbon emissions, would be eliminated over the engine's entire operating temperature range and ring performance could potentially be improved because of less piston rocking in the bore. Ringless operation would appear to be particularly attractive for high-r/min two-stroke engines where oil-wiper rings are not required and relatively more blow-by may be tolerable.

For simplicity, the figure illustrates a one-cylinder, air-cooled, two-stroke internal-combustion engine that might be built according to this concept (multicylinder and four-stroke engines are also possible). The cylinder barrel would be made of carbon-carbon composite sandwiched between an air-cooled metal head and a metal crankcase. This assembly would be held together by long head bolts, which would pass through the head and through (or alongside) the carbon/carbon cylinder barrel into threaded holes in the crankcase. The carbon/carbon cylinder barrel could be sealed to the crankcase with an O-ring and to the head with a head gasket.

The cylinder block could be fabricated with one or more of many possible configurations of fibers in the carbon/carbon material. The simplest and most economical configuration would be a stack of plies in which all fibers are aligned perpendicular to the axis of the cylinder bore. The inherently low interlaminar strength of the carbon/carbon block would not be a major concern because the clamping force applied by the head bolts would negate cross-ply tensile stresses in the laminate. In principle, this configuration could likely be chosen to maintain the close-tolerance piston/cylinder clearance because it would exploit two

features of carbon fibers that are very attractive in this application: high lengthwise thermal conductivity (for some fibers, greater than that of copper) and nearly zero lengthwise thermal expansion. This configuration would minimize thermal expansion of the cylinder bore while maximizing the outward conduction of heat through the cylinder barrel to the ambient air. In practice, some circumferentially oriented fibers would also be needed to provide reinforcement against hoop stresses, but the proportion of such fibers should be minimized.

Fabrication of the cylinder barrel could begin with stacking the plies in a mold that could include an inner mold die roughly the size of the cylinder bore. Alternatively, the cylinder bore could be machined somewhat undersize prior to carbonization. In either case, the initial formation of the bore would expose the inner edges of all the plies to impregnating materials, which would be applied during densification steps. Eventually, the cylinder bore would be machined to near the final diameter, then the inner surface of the cylinder would be treated in sealing and coating processes to reduce friction and protect against oxidation. The cylinder would then be honed to its final diameter.

This work was done by Philip O. Ransone of **Langley Research Center**. *No further documentation is available.*

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Langley Research Center; (757) 864-3521. Refer to LAR-15094.

Modular, Highly Maintainable, and Flexible Control Software

This software also lends itself to multitasking and distributed processing.

Marshall Space Flight Center, Alabama

Model Rocket Engine Software System (MRECS) is a system of control software that was originally intended for use in controlling rocket engines but is also applicable to almost any real-time, closed-loop process-control system — for example, the feedback control system of a robot. MRECS affords the capabilities necessary for feedback control, actuation of valves and other devices by use of discrete and/or analog commands, processing of sensor readings, and generation of alarms by comparison of various quantities with limiting values. MRECS is capable of real-time multitasking and is amenable to distributed processing. It is designed, from the outset, to be highly maintainable and to be flexible in the sense that, in response to changing requirements, it can be quickly and reliably modified and tested.

In previous efforts to develop rocket-engine-control software, there was an emphasis on minimizing the costs of development. However, the costs of maintenance and operations are significant parts of total life-cycle costs. In the development of MRECS, there has been less emphasis on limiting the cost of development and more emphasis on utilizing modularity and flexibility to reduce the costs of maintenance and operations.

MRECS takes advantage of the inherent support for modularity in the Ada programming language to implement real-time multitasking. Of all the engine-control programs in the experience of personnel at Marshall Space Flight Center, MRECS is the first to use real-time, preemptive priority-scheduled multitasking, the first to run on a commercial off-the-shelf (COTS) real-time operating system, and the first to use the standard Transmission Control Protocol/Internet Protocol (TCP/IP) for both command input and telemetry output. Through the use of Ada and COTS system software, MRECS has been made transportable to a variety of state-of-the-art computers and operating systems. In use, the worth of MRECS has been proven in that MRECS has been shown to be adaptable to different engine configurations and characteristics, to be amenable to rapid modification, and to perform engine-control functions reliably.

This work was done by Robert L. Stevens and Richard H. Beckham of **Marshall Space Flight Center**. *For more information, contact the Marshall Commercial Technology Office at 256-544-2615. MFS-31417*

Low-Plasticity Burnishing

Fatigue life and resistance to damage are increased at relatively low cost.

John H. Glenn Research Center, Cleveland, Ohio

Low-plasticity burnishing (LPB) has been developed as an affordable means of imparting residual compressive stresses to surface layers of metal parts (especially engine components) in order to increase their fatigue lives. Heretofore, surface compressive stresses to enhance the fatigue lives have been produced, variously, by shot peening or laser shock peening. Unfortunately, thermal relaxation has been found to result in loss of the needed surface-layer compressive stresses, with consequent shortening of component lives and reduction of engine performances. Hence, what is needed is a means of imparting thermally stable surface compression.

In the LPB process, a smooth, free-rolling spherical ball is pressed against and rolled along the surface of the workpiece to be burnished. The ball must be hard, and it must have a high modulus of elasticity and a high yield strength. To ensure free rolling, the ball is supported in a spherical-socket fluid bearing (see figure) with sufficient fluid pressure and flow to maintain the ball out of contact with the socket. The force with which the ball is pressed against the surface is made large enough to deform a surface layer of material into a state of compression, taking account of any tensile stress that might exist in the workpiece prior to burnishing.

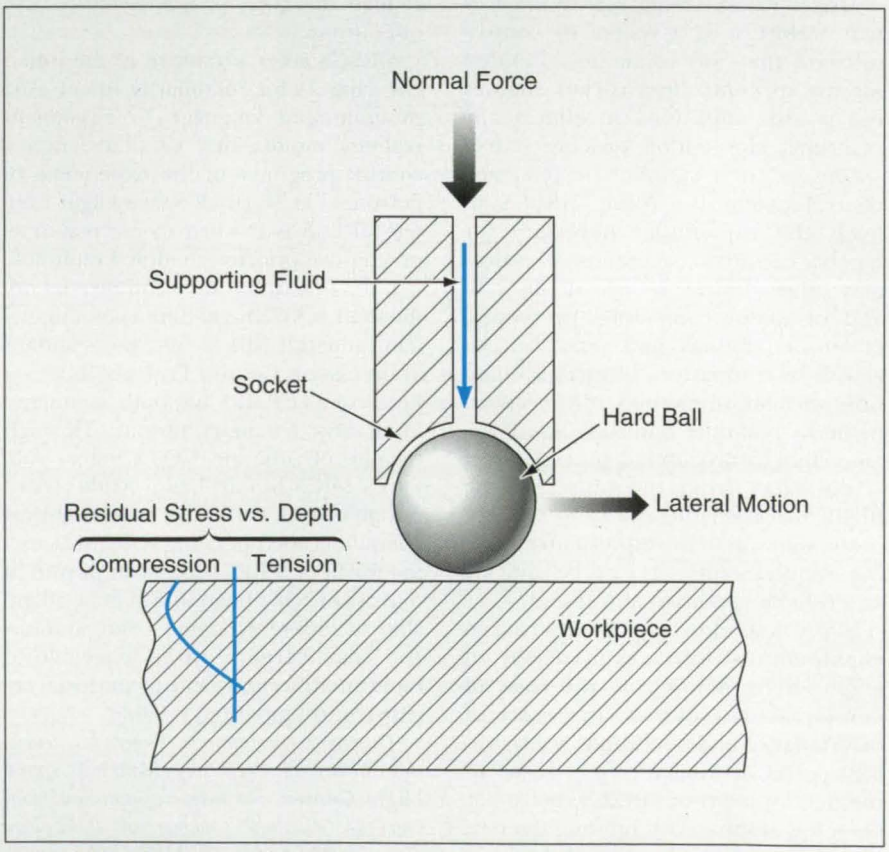
By use of the positioning capability of a computer numerically controlled (CNC) machine tool, the ball is moved along the surface in a raster or other suitable pattern to cover the surface in a series of passes at a controlled separation chosen to obtain maximum compression with minimum cold working. LPB is not limited to flat workpieces: In the case of a complexly shaped workpiece, the positioning capability of a multiaxis CNC machine tool can be exploited to move the ball on any desired path across the surface, as in a typical multiaxis CNC machining operation.

LPB produces minimal cold work, imparting greater (in comparison with shot peening and laser shock peening when performed with multiple shocking cycles) resistance to thermal relaxation at high temperature. The resulting greater retention of surface compression at engine operating temperatures results in substantial increases in fatigue lives and in retardance of the growth of pre-existing cracks. In addition, LPB increases resistance to damage by impacts of foreign objects.

LPB costs less than does laser shock peening and offers greater depth and stability of the compressive layer, relative to shot peening. Because LPB can be performed easily during manufacturing by use of conventional CNC machine tools, there is no need to ship components to separate facilities for LPB. The process can be readily accommodated in an existing machine shop environment. Both the capital cost of LPB equipment and the unit cost of component processing typically are an order magnitude less than for laser shock peening.

This work was done by Paul S. Prevey III of Lambda Research for **Glenn Research Center**. *Technical assistance was provided by Glenn researchers of the Material Division and Structures Division, working on the ULTRASAFE PROJECT'S Crack Resistant Disk Materials SUB-PROJECT. For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com/tsp*** *under the Manufacturing category.*

Inquiries concerning rights for the commercial use of this invention should be addressed to NASA Glenn Research Center, Commercial Technology Office, Attn: Steve Fedor, Mail Stop 4–8, 21000 Brookpark Road, Cleveland, Ohio 44135. Refer to LEW-17188.



A **Hard Sphere in a Spherical Fluid Bearing** is pressed against and rolled along the workpiece, deforming a surface layer into a state of compression.

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System for Detecting Hazardous Gases at Multiple Locations

John F. Kennedy Space Center, Florida

The Hazardous Gas Detection System 2000 (HGDS 2000) is the latest in a series of instrumentation systems for detecting gases leaking from a space shuttle on a launch pad. The HGDS is a fully redundant system that includes analog and digital electronic control circuitry and a subsystem for sampling gases at multiple locations and delivering the samples to two independent commercial quadrupole mass spectrometers. [The sampling subsystem was described in "System for Delivering Gas Samples to Multiple Instruments" (KSC-12123), *NASA Tech Briefs*, Vol. 25, No. 6 (June 2001), page 60.] The system is rugged enough to withstand the launch-pad environment, is easy to operate, and can be fully automated. When in automated operation, the system notifies an operator if an unusual situation or a fault is detected. An operator interacts with the system via a personal computer by use of mouse and keyboard commands. Operation of the HGDS 2000 is expected to take substantially smaller amounts of operators' time and to cost substantially less, relative to operation of the older instrumentation systems in this series. Although the HGDS 2000 is optimized for detecting leaking spacecraft-propellant gases, it can also be used to detect many other gases.

This work was done by Carolyn Mizell and Greg Breznik of **Kennedy Space Center** *and Tim Griffin, Guy Naylor, William Haskell, Richard Hritz, David Floyd, and Charles Curley of Dynacs, Inc. Inquiries concerning this invention should be addressed to the Technology Commercialization Office, Kennedy Space Center; (321) 867-8130.*
KSC-12250

Temperature-Compensation Method for High-Temperature Strain Gauges

Strain gauge and temperature-compensation element are exposed to the same temperature.

Dryden Flight Research Center, Edwards, California

A relatively simple and inexpensive method of fabricating a temperature-compensation element for high-temperature strain gauges has been devised. This element, connected in the adjacent arm of a Wheatstone bridge, provides temperature compensation for an active strain gauge attached to the substrate. A method for accurately measuring structural static strains in harsh environments is an important requirement for future flight research of hypersonic vehicles and ground test articles. Sturdy, flight-worthy strain sensors must be developed for attachment to superalloys, new composite materials, and thermal-protection systems. With little deviation from standard Rokide flame-spray installation procedures, preliminary tests indicate viable data can be produced to operating temperatures of at least 1,700 °F (927 °C).

In the present method, the temperature-compensation element is encapsulated and insulated in alumina by the Rokide flame-spray process and used as an inactive element in a half-bridge configuration. An inactive element, or gauge, is often also referred to as a "dummy gauge" because it does not sense surface strains; in other words, there is no mechanical strain transfer from the substrate to the gauge filament. The temperature-compensation element is mounted in close proximity to the attached, or active, strain gauge. Adequate surface contact of the compensation element to the test article must be achieved in order to maintain good thermal conductivity. However, unlike the active strain gauge, the temperature-compensation element is not rigidly attached to the substrate which is to be measured; instead, the temperature-compensation element (see Figure 1) is attached flexibly to the substrate using nickel/aluminum-alloy straps.

Configured as a half-bridge, the temperature-compensation element is connected in an arm of a Wheatstone bridge adjacent to an arm containing the active strain gauge. The temperature-compensation element does not sense mechanical surface strains, but it is subjected to the same temperatures as is the active strain gauge. Inasmuch as equal changes in adjacent arms of a

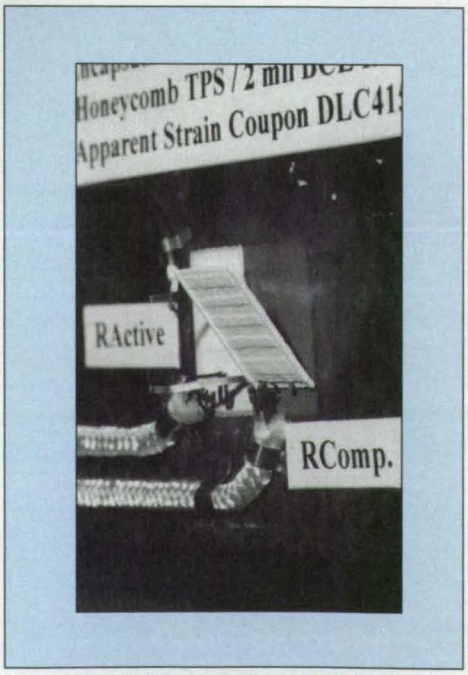


Figure 1. The **Active Strain Gauge and the Temperature-Compensation Element** are labeled "RActive" and "RComp," respectively. The straps that hold down the compensation element have been removed, and the gauge has been lifted for this photograph. Contact with the substrate must be maintained to ensure thermal conduction in the presence of transient heating.

Wheatstone bridge cancel, the equal temperature-induced components of the changes in the resistance of the active strain gauge and the temperature-compensation element cancel, leaving a Wheatstone-bridge output indicative of only the surface strain in the substrate.

The Flight Loads Laboratory at NASA Dryden Flight Research Center has evaluated and characterized many high-temperature strain-gauge assemblies over the years, maintaining rigorous focus on reducing the thermal output, or apparent strain, of these gauges. High-temperature strain-gauge alloys generate outputs indicative of large magnitude, nonlinear, apparent strains that depend on maximum operating temperature, time at temperature, and rates of cooling. The apparent-strain output of a high-temperature strain gauge consists of three main components: (1) the mismatch in coefficients of thermal expansion between the substrate and the gauge alloy, (2) the thermal coefficient of electrical resistivity of the gauge alloy, and (3) the change in gauge factor as a function of temperature. Characterization of strain gauges at elevated temperatures is critical inasmuch as correction curves must be generated and applied to raw data to determine true mechanical strains from indicated strains.

Prototype temperature-compensation elements, according to the present method, were wired with active high-temperature strain gauges as half-bridges. Both the temperature-compensation element and the active strain gauge were made of 0.002-in. (0.05-mm) Fe/Cr/Al-alloy wire. The active strain gauge was attached and insulated to the substrate using standard NASA Dryden plasma spray (precoat) and Rokide flame-spray procedures, while a modified version of the procedure was used in fabricating the temperature-compensation elements.

Preliminary apparent-strain tests of the present method of temperature-compensation at temperatures up to 1,700 °F (927 °C) were performed. The compensated half-bridge outputs were more nearly linear and repeatable, and of less magnitude, than those of the strain gauges in the uncompensated quarter-bridge configuration. Early results indicate that effective cancellation of the effects of temperature-induced changes in the electrical resistance of the active strain gauge and the temperature-compensation element was achieved. Numerous undesired attributes of high-temperature strain gauges used in the quarter-bridge configurations were reduced when thermally compensated by present method (see Figure 2). These attributes include zero shifts (sensor non-return to zero) as a function of cooling rates, rates of drift during static holds, and uncertainties in the phase transformations of gauge alloys.

Two problems observed in bare-wire temperature-compensation elements have also been eliminated using the present method. These problems include slope change of the overall apparent-strain curve from one cycle to the next cycle, and excessive drift at high temperatures. A "cycle" refers to both the heat-up and cool-down portion of a test. These changes in slope from cycle-to-cycle and excessive drift rates do not occur in the gauges fabricated and used according to this method because the active gauge and the temperature-compensation element are under the same condition; they are both encapsulated

in alumina, therefore, subjected to the same oxidation environment. In contrast, a bare-wire temperature-compensation element oxidizes differently than the active gauge since it is not encapsulated in alumina. In addition, heat conduction will often be quicker to a bare-wire element (lower mass) when compared to the encapsulated active gauge. This temperature lag in the active gauge becomes more pronounced as transient heating rates increase causing the electrical resistance cancellation of the half-bridge to be less effective.

This work was done by Anthony Piazza of **Dryden Flight Research Center**.

This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, Dryden Flight Research Center; (805) 258-3720.

Refer to DRC-96-74.

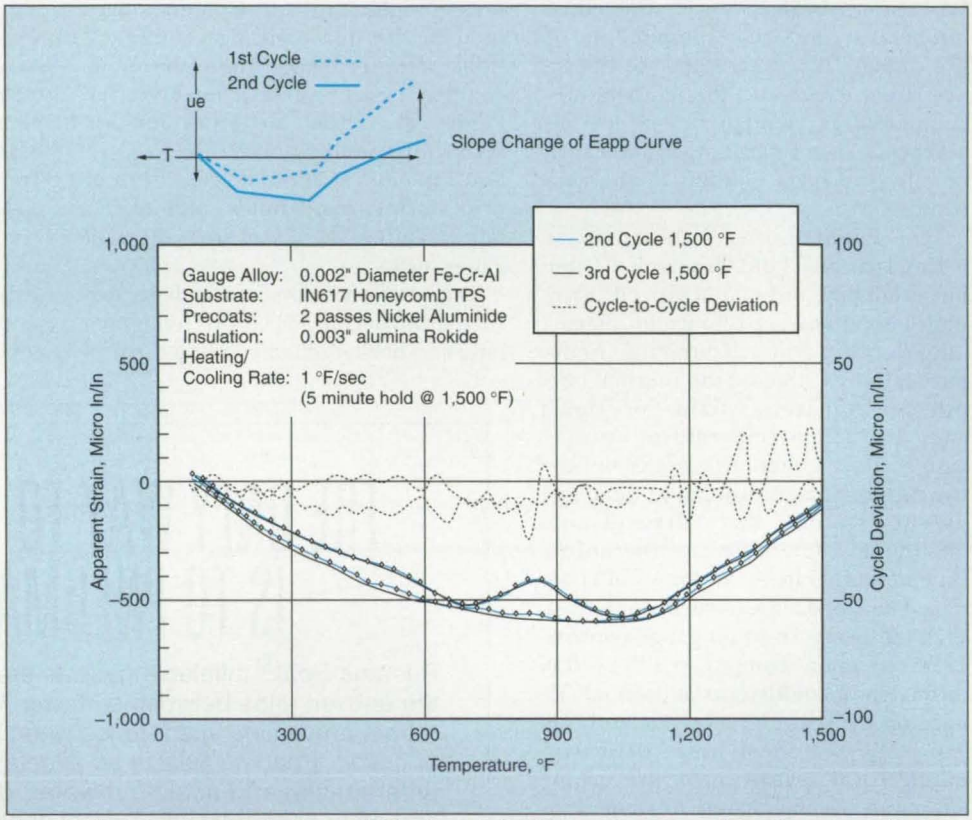


Figure 2. These **Apparent-Strain Curves** obtained by a half-bridge strain gauge utilizing the presented temperature-compensation element exhibit little zero shift, a low rate of drift at 1,500 °F (≈820 °C), less nonlinearity (in comparison with uncompensated strain gauge), a high degree of cycle-to-cycle repeatability, and no cycle-to-cycle slope changes.

Windowed Revocation of Public-Key-Encryption Certificates

The costs of computation and communication are less than in prior certificate-revocation techniques.

John F. Kennedy Space Center, Florida

Windowed revocation is a technique for the revocation of the digital certificates that provide assurance of the authenticity and integrity of public encryption keys and associated private decryption keys. These keys are used to protect the privacy of communications via the Internet. The need for revocation of certificates arises in cases in which private keys are lost or compromised, rights of access are changed, or it is desired to change keys as a precaution against cryptanalysis. Windowed revocation satisfies the security requirements and conforms to the policies of public-key systems now in use, while imposing less (relative to prior certificate-revocation techniques) of a burden on certificate server computers and communication networks.

Heretofore, the acceptance of certificate-distribution services has been inhibited by the lack of a certificate-revocation technique that is scalable in the sense that the cost associated with the management, retrieval, and verification of certificates would increase at a rate less than the rate of growth of the community served. There are two fundamental approaches to the distribution of information about revocation of certificates: explicit and implicit.

- In certificate-distribution architectures that employ explicit revocation, each issuer explicitly states which certificates are revoked, and indirectly which are not revoked. In systems based on the X.500 standard, each issuer periodically generates a list of certificates that have been revoked but have not yet expired. The presence of the certificate in the list, called a certificate revocation list (CRL), explicitly states revocation. The performances of such systems are largely limited by the cost of bandwidth: the transmission of large CRLs to potentially many clients can be prohibitively expensive.
- In certificate-distribution architectures that employ implicit revocation, lack of revocation is asserted implicitly through the verifier's ability to retrieve the certificate. Any certificate retrieved from the issuer is guaranteed to be valid at or near the time of retrieval. Associated with each certificate is a time to live (TTL), which represents the maximum time the certificate may be cached. Thus, in implicit revocation, the window of vulnerability is the TTL. The performance of a system that uses implicit revocation is limited by the cost of acquiring certificates: supplying real-time information on revocation status during each acquisition is computationally expensive.

Windowed revocation involves a hybrid of explicit and implicit revocation that affords the desired scalability. In windowed revocation, the issuer asserts revocation in two different ways at two different times: (1) implicitly during initial acquisition of a certificate, and thereafter (2) explicitly through periodically published CRLs. Verifiers acquire CRLs from issuers directly. Retrieved certificates are guaranteed to be nonrevoked, fresh, and authentic. Subsequent validation of the revocation statuses of certificates is effected primarily through CRLs.

CRLs are generated at uniform time intervals, each interval being denoted a CRL publication period. Revoked certificates are mentioned in the CRLs that occur during possibly longer intervals denoted revocation windows (see figure). A revocation window is the time during which a certificate may be cached without further validation. The revocation window is specified by the issuer and documented in each certificate. By bounding the times during which each revoked certificate must be included in the periodic CRLs, revocation windows limit the sizes of CRLs and thus the costs of distributing them.

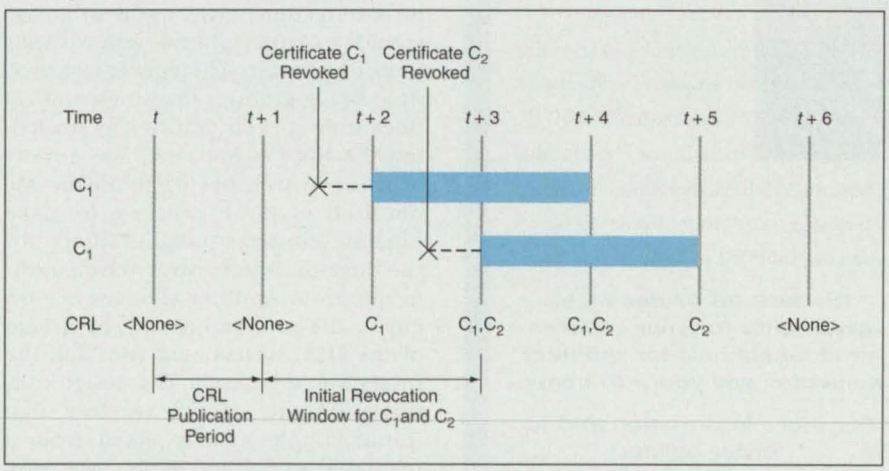
Windowed revocation is secure, and its correctness has been rigorously mathematically proved. In worst-case situations, it requires no more network bandwidth than do prior CRL-based techniques and no more central-processing-unit resources than do prior implicit techniques. Moreover, the tradeoffs between consumption of resources and security can be managed through the parameters of windowed-revocation protocols.

This work was done by Sugih Jamin and Patrick D. McDaniel of the University of Michigan at Ann Arbor for **Kennedy Space Center.**

In accordance with Public Law 96-517, the contractor has elected to retain title to this invention. Inquiries concerning rights for its commercial use should be addressed to

Mitch Goodkin
University of Michigan
Tel No.: (734) 764-4290
E-mail: mgoodkin@umich.edu

Refer to KSC-12149/12208, volume and number of this NASA Tech Briefs *issue, and the page number.*



This **Time Line** illustrates an example of windowed revocation. Once certificates C_1 and C_2 are revoked, they are mentioned in CRLs that occur during their revocation windows.

Books & Reports

Mechanical Event Simulation for MEMS Design

This report examines the simulation of the dynamic behavior of a MEMS (Micro Electro Mechanical Systems) optical switch in order to meet the Telcordia telecommunication industry standards for shock. The setup of the finite element model of the telecommunications device is discussed in detail, along with a description of how optical switching technology will contribute to increased Internet bandwidth.

This work was done by Robert Calvet of **SiWave, Inc.** *utilizing Mechanical Event Simulation software from* **ALGOR, Inc.** *To obtain a copy of this report, visit siwavereport.ALGOR.com.*

Narrowband Tunable Optical Filter Using Fiber Bragg Gratings

Research at Langley Research Center has developed a special fiber-Bragg grating optical filter for use in aircraft or spaceborne differential absorption lidar (DIAL) systems for measuring water vapor in the atmosphere of the Earth. The filter is an optical fiber containing two Bragg gratings that afford high reflectance in 10-pm-wide wavelength bands at wavelengths of 946.0 and 949.5 nm. The optical fiber would be glued to a piezoelectric ceramic, to which a voltage could be applied to stretch the gratings and thereby adjust their peak-reflection wavelengths to correspond to atmospheric water vapor lines of interest. The concept of multiple Bragg gratings in a single optical fiber tuning such gratings by stretching the fiber is not new. The novelty of this research lies partly in the application of these concepts to make tunable ultra-narrowband filters for the specific water vapor wavelengths in question. Another element of novelty in the proposal lies in the design of the DIAL instrument in which the filters would be used: The design calls for a unique optical receiver that would couple a lidar signal from a telescope to a filter of the type proposed, then using an optical circulator the light would be detected.

This work was done by Russell DeYoung of **Langley Research Center.** *To obtain a copy of the report, "Ultra-Narrow Passband Optical Filter for Space Water Vapor DIAL Applications," access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com/tsp*** *under the Physical Sciences category.*

LAR-15978

Technical Background of Special Bus-Driver Software

A short report discusses the technical background of, and the need for, special bus-driver software for part of a test-bed computer system that is to be used in experimentation for development of advanced avionics. The system features a scalable, fault-tolerant, distributed architecture that incorporates a variety of commercial standard bus interfaces. The special bus-driver software is needed to overcome an incompatibility between (1) a Power PC 750 processor made by a first manufacturer and (2) an IEEE 1394 bus-interface circuit board made by a second manufacturer for use in conjunction with a different version of the Power PC 750 made by a third manufacturer. The hardware-related portions of source code of the driver software of the IEEE 1394 board from the second manufacturer was modified and ported to the power PC 750 processor from the first manufacturer. The source code as thus modified has been found to perform successfully and is now in use in the test bed.

This work was done by Minh Lang, Savio Chau, and Tom Huynh of Caltech for **NASA's Jet Propulsion Laboratory.** *To obtain a copy of the report, "IEEE 1394 bus driver software for the Synergy Power PC 750 processor," access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com/tsp*** *under the Information Sciences category.*

This software is available for commercial licensing. Please contact Don Hart of the California Institute of Technology at (818) 393-3425.

Refer to NPO-30284.

Electric Transaxle Drive Systems Power New Aircraft GSE Vehicles

Strenuous efforts are being made by the airline industry to reduce pollution and improve air quality at airports around the globe. Airport ground support equipment (GSE) can be seen dashing back and forth between aircraft, passenger terminals, and other facilities. The internal combustion (IC) engines used in increasing numbers of GSE vehicles are a significant source of airport pollution. To counteract this condition and meet recent state and federal EPA requirements in the U.S., increasing numbers of zero emission electric GSE vehicles are being introduced into the working environment of airports.

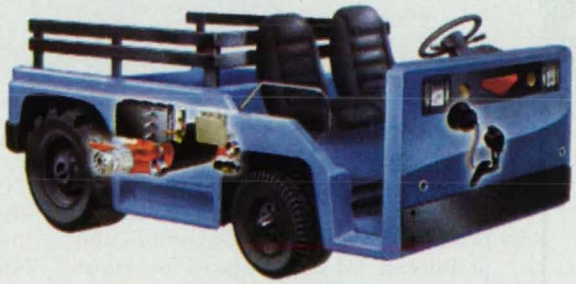
The use of an electric traction drive system eliminates nitrous oxide, carbon dioxide, and other internal combustion engine pollutants. Electric vehicle power systems are much more efficient and cleaner than IC power systems, even when the pollution from the electric power plant is considered.

Real World Application — Baggage Tractor

Many types of GSE vehicles provide the necessary mobility to move passengers, cargo, and crew into and out of aircraft. Service technicians and mechanics require special mobile lifts to provide critical service and inspection activities. The airport baggage tractor is one of the first GSE applications to begin conversion to all electric drive systems.

Tractor weight is typically 7,000 to 8,000 pounds with battery. The maximum speed can reach 14 miles per hour (mph) with a 25,000-pound load. The draw bar pull required is 3,500 to 4,000 pounds. These tractors are able to accelerate to 15 mph in less than 12 seconds when pulling a 7,000 pound load.

Developed with input from six major airlines, the recently introduced integrated 80 Volt AC electric drive system is designed for GSE vehicles rated up to a 5,000 pound static drawbar pull and a top speed of 20 mph. Ballard Power Systems' Ecostar powertrain has been installed in aircraft ground support vehicles manufactured by Stewart and Stevenson TUG, Charlatte, Eagle Industrial Truck, Fleet Body Equipment, and others. Today these vehicles are being used at many airports, including Chicago's Midway and O'Hare, Tulsa, Oklahoma City, San Francisco, Atlanta, Houston (IAH), Denver, and Toronto.



GSE vehicle featuring Ballard's Ecostar system.

The Ecostar system, which meets the EPA's zero emission program, currently provides six major components, all integrated to function as a single vehicle drive and control system for this application:

1. Transaxle power transmission assembly.
2. 80V AC system controller, using a torque-based vector control algorithm, with MOSFET power devices; system includes contactors and fusing.
3. Hydraulic brake line pressure sensor for dynamic regenerative brake control.
4. Electronic accelerator pedal assembly (first used in the Ford Electric Ranger).
5. DC/DC Converter, provides 400 watts of 12V DC power for vehicle systems.
6. Battery state-of-charge display gauge with a seven-character LCD readout.

The system electronics are passively cooled via a panel mounted directly to the vehicle's chassis. The AC induction motor and axle assembly are mounted directly to the vehicle chassis for mechanical rigidity. The transaxle attaches to the vehicle using two metal-elastic pivot bushings and uses coil springs and shock absorbers. Any DC power source such as 80V flooded lead acid batteries of today or fuel cells of tomorrow can power the electric drive system.

Transaxle Assembly

The drive axle (transaxle) assembly is composed of a drive axle, AC motor, planetary gear reduction, and wet disc brakes all integrated into a single co-axial assembly. The overall transmission gear reduction is approximately 25:1. Low gear noise is achieved by the use of helical gears in the planetary gear train assembly. The transaxle drive system transmission can pull a GSE vehicle up an 18% grade while pulling 7,800 pounds of baggage or cargo.

AC Induction Motor Operation

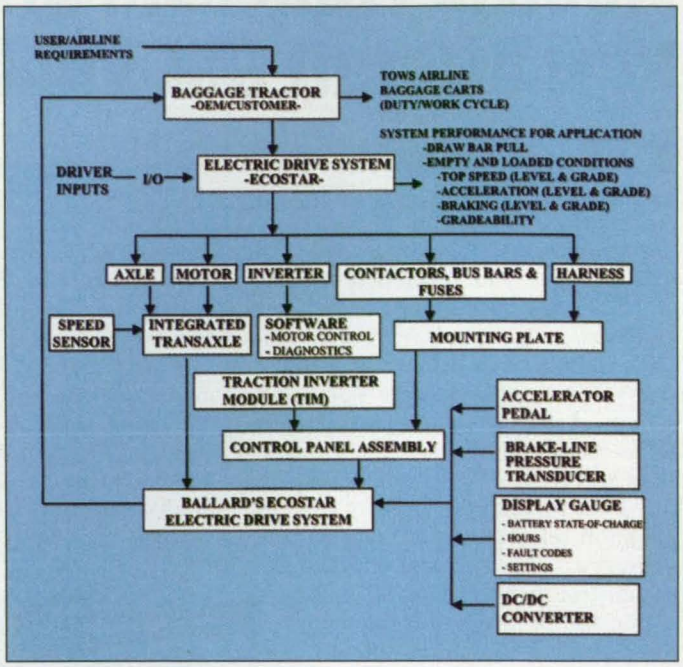
The AC induction motor is a brushless motor that has been used in general appliance and factory applications for decades. The 4-pole, 3-phase AC motor operates up to 6,000 rpm and 225 foot-pounds of torque. The AC motor reaches a peak power level of 40 horsepower. Power is rated at 35 horsepower of continuous operation up to 60 minutes. The motor's operating ambient temperature covers the range of -31° F to +123° F. The AC motor includes a temperature sensor located in the stator windings for protection from extreme conditions.

Inverter Power Stage Topology

The electronic drive system utilizes an inverter power stage and inverter control board that interfaces to the AC induction motor. The inverter power stage

uses a 6-switch MOSFET based power bridge drive configuration to convert DC battery power into AC inverter power. The inverter power stage sequentially energizes the 3-phase AC motor at a pulse-width modulation (PWM) frequency of 8 kHz over a wide output frequency range of 0 to 250 Hz. Peak inverter power stage efficiencies reach 95%. The compact 7.87" (L) x 11.02" (H) x 3.15" (W) overall package (weighing less than 32.3 pounds) develops a peak power of 47 horsepower for up to 2 minutes. A current level of up to 500 amps rms (for 2 minutes) at 122° F ambient drives the AC motor at desired torque levels. This level of current is compatible with, but always lower than the drive current levels from traditional DC series-wound traction motor drive systems.

Passive cooling (i.e., no fans required) and adjustable current control are used to keep the inverter operating temperature within safe limits. Bus voltage is maintained between 60 volts and 100 volts at full rated power. Phase voltage is also continuously monitored for any unusual waveform conditions found in any of the 3 AC motor-stator phases.



A typical GSE Electric Drive System with Subsystem.

Inverter Control Board Operation

The inverter control board uses a patented advanced vector control algorithm to operate the AC induction motor over a range of 0 to 6,000 rpm with precise torque control capabilities. It provides time responsive, smooth and reliable torque production. The vector control scheme efficiently provides for both high torque and high speed to maximize battery usage. The inverter control board monitors inverter enclosure and motor temperatures, bus voltage levels, power stage voltage levels, and other diagnostics through a number of digital and analog input-output (I/O) devices.

Regenerative braking is provided and the charge level and rate of recharging is programmable up to the defined limits. The braking system can capture regenerated energy almost down to zero speed. The inverter control board receives input control signals from the electronic throttle control and brake pressure transducer for fast responsive vehicle control. The power steering and input line switch (contactor) status are also inputs to the inverter control box and used for monitoring vehicle safety.

Most motor control and vehicle control performance parameters are programmable. The control of key operating parameters' adjustment is divided into 3 levels. The supplier adjusts low-level parameters, the vehicle manufacturer adjusts mid-level parameters, and end users adjust the high-level parameters. High-level parameters typically include top vehicle speed (forward and reverse), battery type (this allows for more precise battery state-of-charge reporting), level of regenerative braking, and inching parameters to name a few.

In conclusion, the availability of newer generations of power devices, control ICs, and software algorithms will fuel a continual evolution of new cost effective transaxles for electric vehicles, GSEs, and other off-road vehicles.

This article was authored by Kevin Vogler of Ballard Power Systems — Electric Drives Group. The author can be contacted at kvogler@ford.com. For more information on Ballard Power Systems (Dearborn, MI), visit www.ballard.com.

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Advances in Cooperative Transport by Two Mobile Robots

Two mobile robots move in formation while transporting a long payload.

NASA's Jet Propulsion Laboratory, Pasadena, California

Special gimbal mechanisms and algorithms that implement decentralized compliant control have been developed for use in research on the sensors, the actuators, and the design and functional requirements for systems of multiple mobile robots cooperating in site-clearance and construction operations. The gimbal mechanisms and control algorithms were designed, in particular, to enable two robotic exploratory vehicles (i.e., rovers) to transport a long payload while moving along the ground in a commanded formation. Although these developments are parts of a continuing effort to develop robotic capabilities for exploration of Mars, the same robotic capabilities could be expected to find application on Earth.

Figure 1. The **Gimbal Mechanism** enables the gripper to move freely in one translational and three rotational degrees of freedom, and measures forces and torques.

Each gimbal mechanism (see Figure 1) has four degrees of freedom. One such mechanism is part of each rover. The gimbal incorporates a compliant gripper on a longitudinal slider

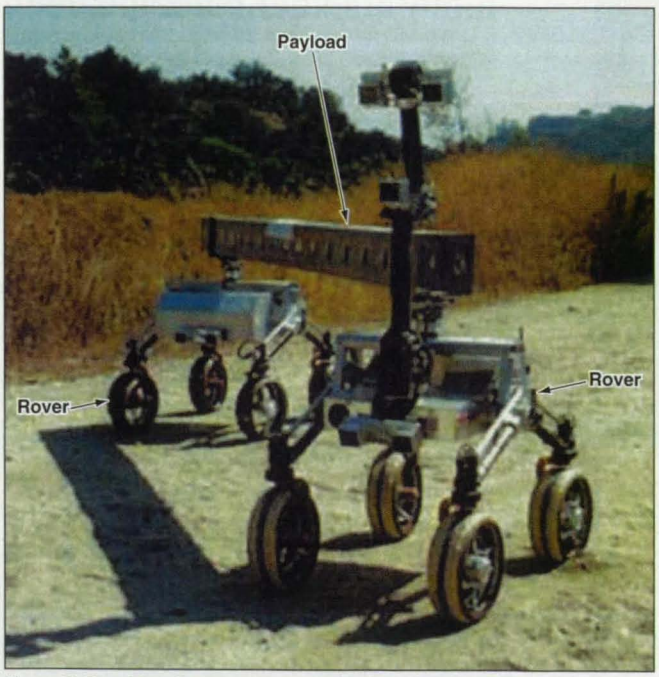


Figure 2. **Two Mars Rovers** transport a long payload in diagonal formation.

for "soft grip" of a payload. The gimbal is passive and is fully instrumented with potentiometers to measure the orientation and position (pitch, roll, yaw, and lateral translation) of the gripper. The gimbal mechanism is mounted on a six-degree-of-freedom load cell, which is used to resolve reaction forces. The load cell, in turn, is mounted on a cross brace between shoulders of the robotic vehicle.

The decentralized compliant control scheme uses no explicit communications; i.e., the rovers do not "talk" to each other via wireless modems but communicate with each other implicitly via their common payload through force sensors. The scheme involves four low-level behaviors denoted formation controller, minimize forces/torques on payload, center payload in longitudinal slider, and group formation. The control inputs for three of the behaviors are the speed and heading of a rover. The formation controller behavior receives a formation-angle command from the group formation behavior. The commanded formation angle is mapped to the corresponding gimbal yaw angles on the two rovers. The formation controller behavior then seeks to control the speed and heading of each rover in an effort to achieve and maintain the commanded gimbal yaw angle on each rover.

The minimize forces/torques on payload behavior seeks to minimize the forces on the payload or compliant linkage on each rover. The forces on the payload can be high if the relative speed between the two rovers is greater than a set threshold. The magnitude of the force along the longitudinal axis of the payload is the input for this behavior. The predominant control output of the minimize forces/torques on payload behavior is a rover speed command, supplemented with steering-correction commands.

The center payload in longitudinal slider behavior seeks to minimize deviations of the payload from midpoint of the longitudinal slider on each rover. The control outputs of the center payload in longitudinal slider behavior are a rover-speed and heading (steering) control command.

Proportional-plus-derivative (PD) controllers for speed and heading modifications that satisfy the requirements for the formation controller and center payload in longitudinal slider behaviors under steady-state conditions have been developed. The PD controllers independently achieve their respective goals, but when implemented simultaneously, they give conflicting speed and heading corrections. To resolve these conflicts, the outputs of the PD controllers are combined by use of a weighting scheme to compute speed and heading corrections for each rover.

In several experiments performed at Arroyo Seco in Pasadena, California, the following actions were demonstrated:

- A pair of Mars rovers compliantly coupled to a common payload (see Figure 2) autonomously moved, variously, forward or backward through distances of 5 to 50 m over uneven, natural terrain.
- The pair of rovers compliantly coupled to a common payload autonomously changed formations between arbitrary initial and final formations (including row, column, and diagonal formations).

This work was done by Ashitey Trebi-Ollennu, Hari Das, Anthony Ganino, Hrand Aghazarian, and Brett Kennedy of Caltech for **NASA's Jet Propulsion Laboratory.** *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com/tsp*** *under the Machinery and Automation category.*

NPO-30376

Magnetostrictive Motor and Circuits for Robotic Applications

Notable features include power-factor correction, speed control, and high position resolution.

Lyndon B. Johnson Space Center, Houston, Texas

A magnetostrictive motor and its drive circuit and control system have been designed to be especially suitable for robotic applications in which there are requirements for precise, high-force linear actuators. The motor includes a laminated armature made of the magnetostrictive alloy Tb0.27Dy0.73Fe0.2. The armature is sandwiched between two double-layered, three-phase stators, which are energized to make the armature move linearly in "inchworm" fashion. The total range of linear motion is 25 mm. Like other magnetostrictive motors, this motor offers the advantages (relative to geared-down conventional motors) of reduced weight, extreme ruggedness, fewer moving parts, greater reliability, and self braking when power is not applied.

A capacitor is connected in series with the stator windings to correct the power factor. This or almost any other magnetostrictive motor presents a highly inductive load to its drive circuit and therefore operates at a low power factor in the absence of correction. As in other electrical applications, a low power factor is undesirable because it gives rise to the need for a greater drive potential or drive current than would otherwise be needed to deliver a given amount of power. At its resonance frequency of 470 Hz, the motor windings exhibit a power factor of 0.352, but the series combination of the capacitor and the motor windings exhibits a power factor of 0.989 — close to the ideal value of 1.

Because the speed of the inchworm motion depends on both the amplitude and frequency of the drive current, the control system includes one controller that holds the frequency constant and varies the amplitude and another controller that holds the amplitude constant and varies the frequency. Both controllers utilize proportional + integral compensation and implement an integrator-antiwindup scheme to limit accumulation of position-error signals.

The control system includes a position sensor and a 12-bit analog-to-digital (A/D) converter that processes the sensor output. Because the output swing of the position sensor is only one quarter of the input range of the A/D converter, one could utilize only 10 of the 12 bits (corresponding to a position resolution of 49 μm) if one were to feed the raw sensor output to the converter. Therefore, to make use of full 12-bit resolution of the A/D converter, the sensor output is fed to the converter via an amplifier stage gain of 4. Another amplifier stage with a gain of 39 is also included to demonstrate a capability of precise positioning; a position resolution of ≈1.25 μm is achievable when this amplifier is included in the signal path.

This work was done by James H. Goldie, Won-Jong Kim, Andrew E. Barnett, and William R. Snow of SatCon Technology Corp. for **Johnson Space Center**. *For further information, access the Technical Support Package (TSP)* ***free on-line at www.nasatech.com/tsp*** *under the Machinery and Automation category. MSC-23051*

NEW PRODUCTS

Integrated Offering for Servo Control

ORMEC (Rochester, NY) digital network drives are now integrated with ServoWorks™ from Soft Servo. ServoWorks is a PC-based soft motion software product for real-time motion/CNC control. Up to 16 ServoWire Soft Motion drives can be networked directly to a standard PC using an OHCI-compatible IEEE 1394 adapter and standard FireWire cabling. With ServoWorks, this single PC performs all servo control, including feedback loops and NC path generation.

For Free Info Visit www.nasatech.com/ORMEC

Miniature Stepping Motors

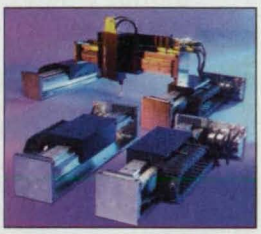
Oriental Motor USA Corp.'s (Torrance, CA) new line of miniature 2-phase hybrid stepping motors are available in two frame sizes: 1.1" (lengths of 1.26", 1.57", or 2.03") and 1.38" (length of 1.46" or 2.05"). These PK Series stepping motors feature a plug-in connector for simple wiring and a compact, lightweight design for flexibility.

For Free Info Visit www.nasatech.com/OMUSA

Precision Linear Slides

High precision AG slides from Optical Gaging Products (Rochester, NY) are designed for applications requiring high accuracy, repeatability, and long-lasting performance. Ironman Ball and Roller Slides combine rigidity and friction-free travel to provide precise motion. The company's patented 'wedge' preload system allows for customization of applications requiring tighter preloads and extends the life and serviceability of the slides.

For Free Info Visit www.nasatech.com/OGP



Linear Motor Actuators

The LMA series of actuators from Aerotech (Pittsburgh, PA) harnesses the speed, acceleration, and accuracy capabilities of a linear motor for the latest in high-throughput linear actuator technology. This modular stage is suitable for pick-and-place machines, gantry axes, shuttle stages, assembly machines, or as a general-purpose positioner. These actuators integrate mechanical and electrical components.

For Free Info Visit www.nasatech.com/Aerotech

High Precision Planetary Gearhead

HD Systems' (Hauppauge, NY) Harmonic Planetary® HPG Series of planetary gearheads incorporates a ring gear design that reduces backlash to less than 1 arc-min for the life of the gearhead. This design eliminates "Backlash Creep," commonly associated with conventional planetary gearing. Available in both flange output and shaft output configurations, applications include packaging, automation, and machine tools.

For Free Info Visit www.nasatech.com/HDS

Dual-Axis Control Module

The SB1292D is the new 120 VAC version of ACSTech80's (Minneapolis, MN) SB1292 dual-axis control module. The SB Series has a multiprocessor, distributed-control design with a 20MHz Intel processor, and a dedicated 80MHz SB2500 Servo Processor per axis for real-time control execution. The universal drive is software configurable for DC brush, AC Servo, and AC induction motors.

For Free Info Visit www.nasatech.com/ACST

Servo Amplifiers

The BX25A20 by Advanced Motion Controls (Camarillo, CA) outputs 25 Amps peak, 12.5 Amps continuous, and operates off 60-200 VDC. Dip-switches enable the user to change current scaling and mode of operation. These units operate in current, open loop, encoder velocity, Hall velocity, and tachometer velocity modes. 1500 VDC isolation is standard on all units. Units are CE compliant and UL recognized. Applications include medical, semiconductor fabrication, and material handling equipment.

For Free Info Visit www.nasatech.com/AMC

Low Profile Encoder

The RCML15 by RENCO Encoders (Goleta, CA) combines brushless motor commutation pulses and incremental position feedback in a low profile (0.35" height) single optical encoder. It features RENCO's patented slide/gap mechanism for ease of installation and a built-in servo groove that allows ±20 degrees rotation for aligning the commutation tracks with the motor poles. Available with resolutions up to 2048 lines, RCML15 provides commutation for 4, 6, or 8 pole brushless motors.

For Free Info Visit www.nasatech.com/RENCO

New on the MARKET

PVC Trim

Trim-Seal® from Trim-lok, Buena Park, CA, is a PVC trim with a sponge rubber tubing attached to provide a mechanical bond to almost any edge, as well as sealing against almost any surface. Operating temperatures are between -20°F and 150°F. The seal is manufactured out of ozone- and UV-resistant EPDM automotive-grade rubber, and the trim is manufactured out of weather- and wear-resistant vinyl. **For Free Info Visit www.nasatech.com/trimlok**

Digital Video Camera

Toshiba America, Irvine, CA, offers the IK-SX1 digital monochrome progressive-scan video camera with asynchronous reset electronic shutter featuring speeds from 1/15 to 1/50,000 sec. The camera has a megapixel 2/3" CCD with 6.45 micron square pixels, and a full scan rate of 15 frames/second at 1392 x 1040 pixel resolution. A partial scan rate allows output of up to 60 frames/second. **For Free Info Visit www.nasatech.com/toshiba**

Product Data Management Software

PTC, Needham, MA, offers Windchill® PDMLink™, part of its Windchill Web-based collaboration and control software. PDMLink captures and manages product information throughout a product's lifecycle in a common database accessible to all users. It allows users to capture and share product structures, definition data, and viewables from CAD systems such as Pro/ENGINEER and AutoCAD. Other features include 3D part visualization and identification, a personal notebook, configuration management, and change management features such as problem reports, enterprise change requests and notifications, and bills of materials. **For Free Info Visit www.nasatech.com/ptc**

Transmitters

The TX1500 transmitters from OMEGA Engineering, Stamford, CT, feature 9-50 V compliance, turndown ratio to 10:1, NMV protection to 120 Vac, -40° to 185°F operation, shock resistance to 55g, and NEMA-4X metal encasing. Two-wire operation power is obtained from a 4 to 20 mA loop without the need for separate power input. Overvoltage of 120 Vac may be applied across the input or output leads for one minute in all models with voltage or thermocouple input. **For Free Info Visit www.nasatech.com/omegaaug**

Design & Simulation Software

The MathWorks, Natick, MA, has introduced SimMechanics, a suite of tools for engineering design and simulation of mechanical systems within the Simulink® environment. SimMechanics provides control engineers with capabilities for model-based design, enabling them to analyze their designs early in the design cycle, evaluate the performance of the system, make adjustments, and eliminate problems before committing to a detailed design. **For Free Info Visit www.nasatech.com/mathworks**

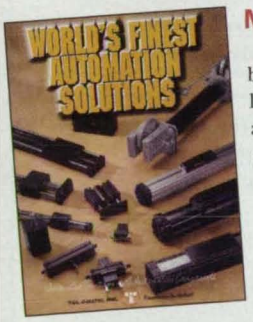
New LITERATURE

Servo Motors

Pittman, Harleysville, PA, offers a 12-page product bulletin on ELCOM SL™ slotless, brushless DC servo motors for imaging, medical devices, mass storage, and office automation equipment. The motors offer negligible magnetic cogging, a magnetic air gap, and speeds of up to 8,000 RPM. **For Free Info Visit www.nasatech.com/pittman**

Electronic Enclosures

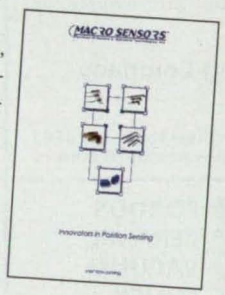
An eight-page brochure highlights electronic enclosure products from Buckeye Enclosures, a division of Buckeye ShapeForm, Columbus, OH. Included are the E-Series, BMX/BMU, XPAND-A, and FC cases, sub racks, and plastic enclosure technology (PET). The enclosures are suitable for data and telecommunications, test and measurement, process control, and medical instrumentation industries. **For Free Info Visit www.nasatech.com/buckeye**



Motion Control Equipment

Tol-O-Matic, Hamel, MN, offers a 12-page brochure on band cylinders, cable cylinders, linear slides, actuators, and grippers. Included are a selection of rod cylinders with force output up to 630 pounds. Options include stop collars, bumpers, adapter plates, stainless steel shafting, shock absorbers, proximity sensors, and switches. The company also custom-builds products for conveyor manufacturers, filter manufacturers, automated banding equipment, and cylinders for the packaging industry. **For Free Info Visit www.nasatech.com/tolomatic**

Position Sensors



An eight-page brochure from Macro Sensors, Pennsauken, NJ, describes AC- and DC-operated linear and rotary position sensors and support electronics. Included are general-purpose LVDTs, hermetically sealed units, spring-loaded LVDTs, and contact-less rotary position sensors. Also available are signal conditioners and controllers. **For Free Info Visit www.nasatech.com/macrosensors**

Heaters

Thermofoil™ heaters and temperature control products from Minco Products, Minneapolis, MN, are detailed in a 60-page catalog. More than 2,000 standard models of etched element heaters with silicone rubber, Kapton™, and mica insulation are included. Also featured are Thermal Clear heaters with transpired insulation and nearly invisible wire elements. **For Free Info Visit www.nasatech.com/minco**

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2002 PRODUCT DESIGN GUIDE ON THE WEB

Pulizzi Engineering, manufacturer of AC power distribution and control systems, has announced its 2002 Product Design Guide that includes standard units, new products, engineering specifications, and a sampling of custom systems. The Web site has a new product search engine that searches the extensive engineering database and submits a list of products to the customer that will meet specific needs. Pulizzi Engineering, Inc.; Tel: 714-540-4229 or 800-870-2248; email: sales@pulizzi.com; www.pulizzi.com

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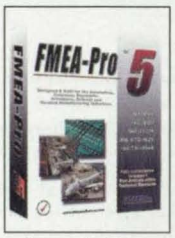

FMEA SOFTWARE

Failure Modes and Effects Analysis using FMEA-Pro™ 5 empowers automotive, consumer, electronic, aerospace, defense and general manufacturing industries to improve the quality, reliability and safety of their products. This fully customizable software helps companies comply with QS 9000, ISO 9000, SAE J1739, MIL-STD-1629, ISO/TS 16949 and other regulations. FMEA-Pro™ 5 contains extensive libraries and data protection features. The report generation tools support a variety of file formats, including HTML and PDF. Download a free trial: www.fmeasoftware.com.

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HIGH-QUALITY SCREENS AND FILTER MATERIALS

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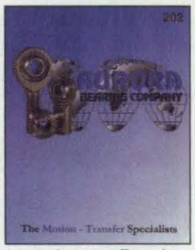

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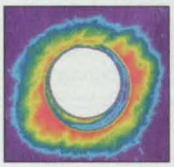

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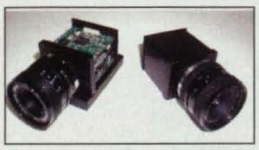

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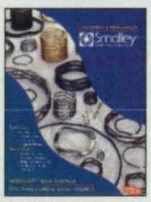

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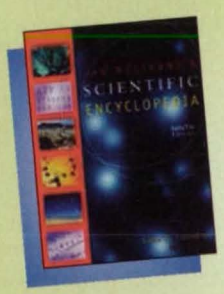

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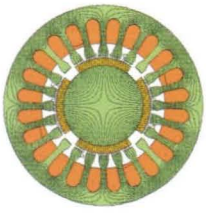

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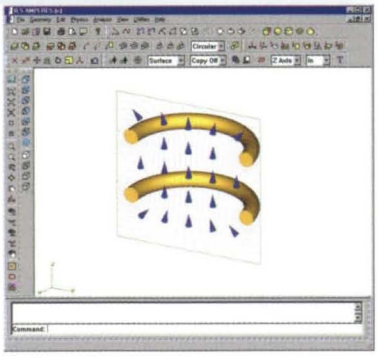

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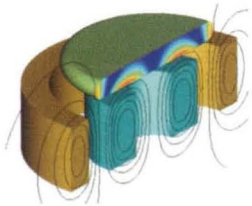

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